8-20-2017

The role of bio-char as an agro-environmental tool: Formation mechanism and potential for control water release, bacterial retention and greenhouse gas emissions

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The Role of Bio-char as an Agro-environmental tool: Production, Potential for Control Water Release, Bacterial Retention and Greenhouse Emissions

Manuel Garcia-Perez, Waled Suliman, Matt Smith

Conference: Bio-char: Production, Characterization and Applications

Engineering Conference International
August 20-25
Hotel Calissano, Alba, Italy

Outline

- Introduction
- Control Water Release
- Bacterial Retention
- Greenhouse emissions
- Conclusions

Suliman W, Harsh JB, Abu-Lail N, Fortuna A-M, Dallmeyer I, Garcia-Perez M: Influence of feedstock source and pyrolysis temperature on biochar bulk and surface properties. Biomass and Bioenergy 2006, 84, 37-48

Smith M, Su H, Amonette J, Dallmeyer I, Garcia-Perez M: Enhancing cation exchange capacity of chars through ozonation. Biomass and Bioenergy 2015, 83, 304-314

Suliman W, Harsh JB, Abu-Lail N, Fortuna A-M, Dallmeyer I, Garcia-Perez M: Modification of biochar surface by oxidation:Role of Pyrolysis temperature. Biomass and Bioenergy, 2016, 85, 1-11

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INTRODUCTION

Evolution of Pyrolysis Research

Ancient Times

The relationship between **humankind and fire** has been documented in the myth of **prometheus**, who stole fire from the gods to give it to man.

Magnificent **charcoal drawing** in the Grotte Chauvent (over **38,000 Years old**) suggest that charcoal was **the first synthetic material produced by man**. Shallow pits of charcoal were **needed to melt tin for the manufacture of bronze tools**[1].

Ancient world **produced charcoal and mastered the recovery of distillation products** macedonians practiced charcoal burning in pits for the purpose of obtaining tars. **Charcoal burning is as old as the use of metals.**

Antal MJ, Gronli M: The Art, Science and Technology of Charcoal Production. *Ind. Eng. Chem. Res.* 2003, 42, 1619-1640.

INTRODUCTION

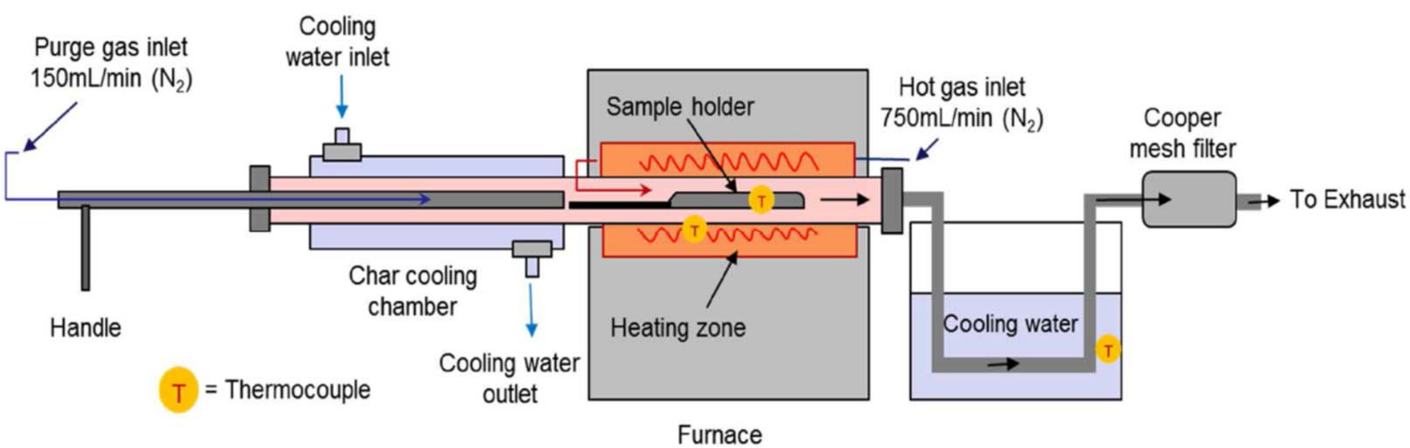
Technology used in developing Countries (44 million tons of bio-char produced in Africa (FAO 2000)). Today: $ 11 billion industry, Employing 12 million people, 2.4 billion people use biochar as domestic fuel.

Biochar Properties

Biomass feedstock composition

Feedstock	C	H	N	O*	Ash
Pine Wood	51.3	8.2	0.4	40.00	0.3
Pine Bark	53.4	7.6	0.8	35.81	2.4
Poplar wood	50.4	7.8	1.2	39.37	1.0

A scheme of the lab-scale spoon pyrolysis reactor



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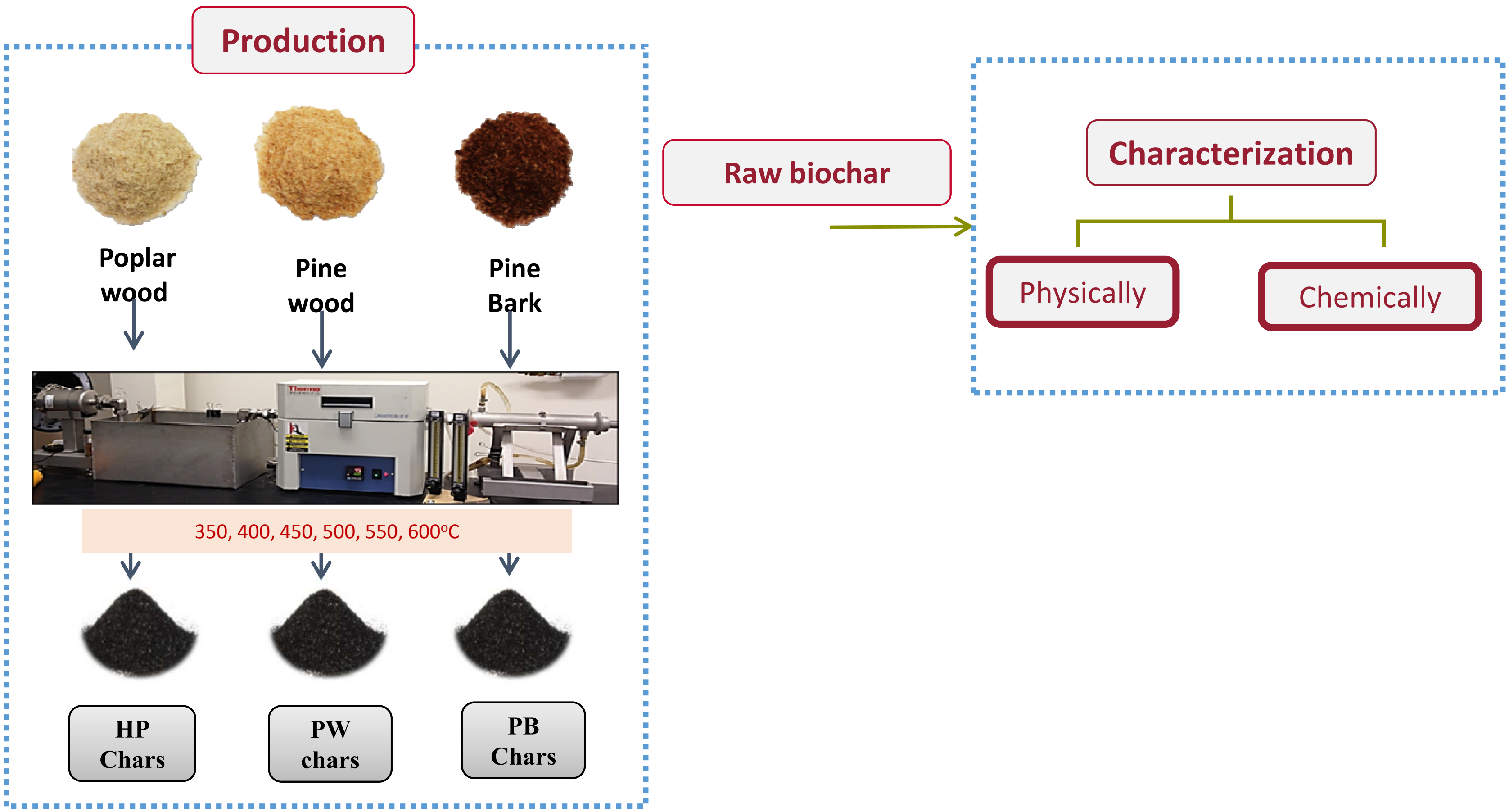
Biochar Properties

Effect of Pyrolysis Temperature



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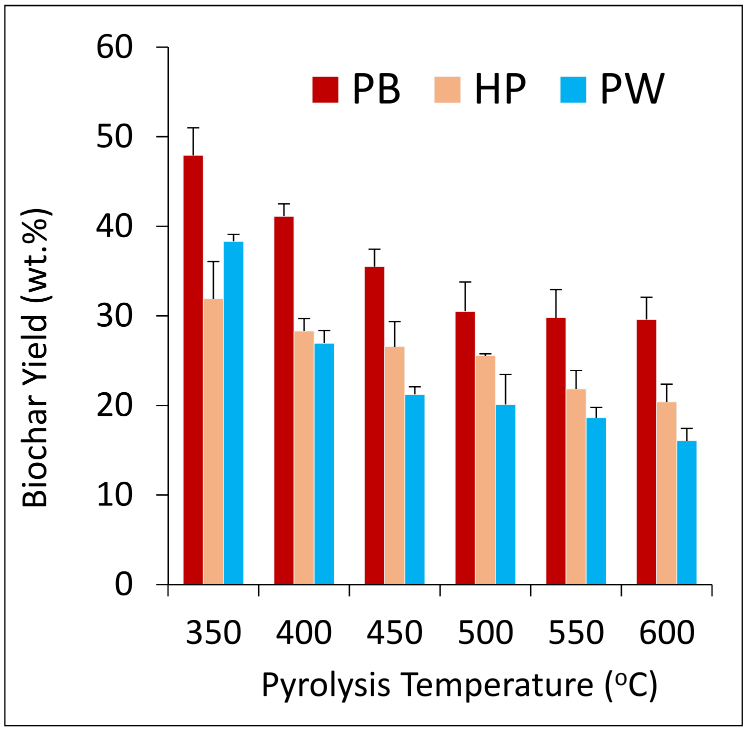
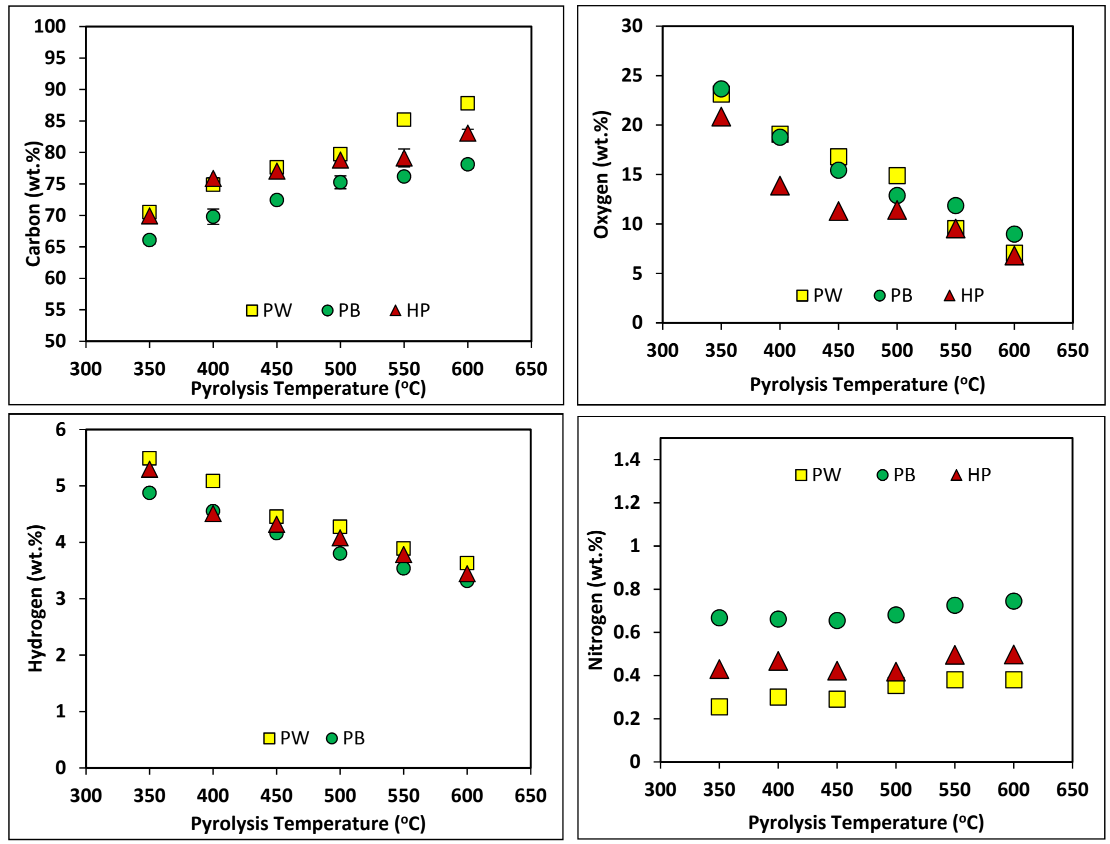
Biochar Properties

Effect of Pyrolysis Temperature

Yield of Char



Elemental Composition



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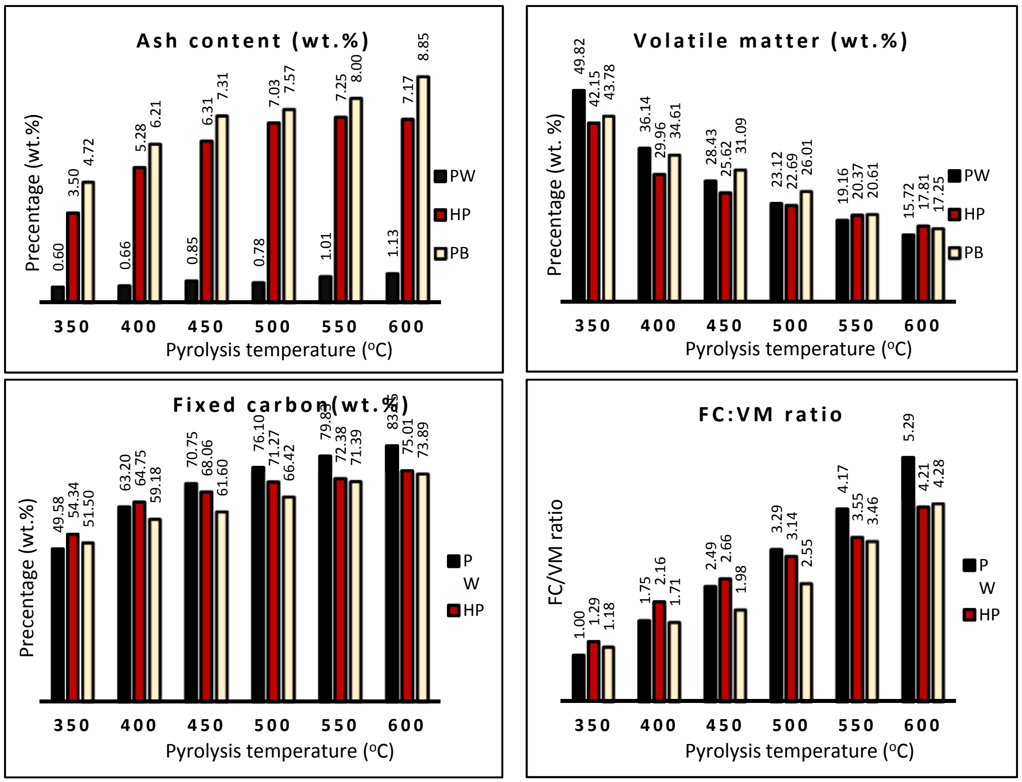
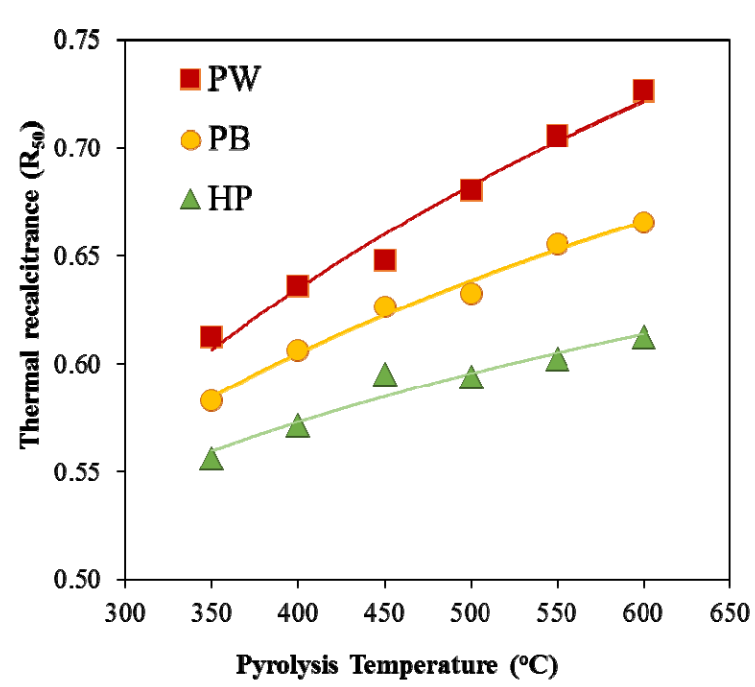
Biochar Properties

Effect of Pyrolysis Temperature

Proximate analysis



Thermal recalcitrance



$$R_{50,\ biochar} = T_{50,\ biochar} / T_{50,\ graphite}$$

$T_{50,\ biochar}$ and $T_{50,\ graphite}$ were the temperature values corresponding to 50% weight loss by oxidation/volatilization of biochar and graphite

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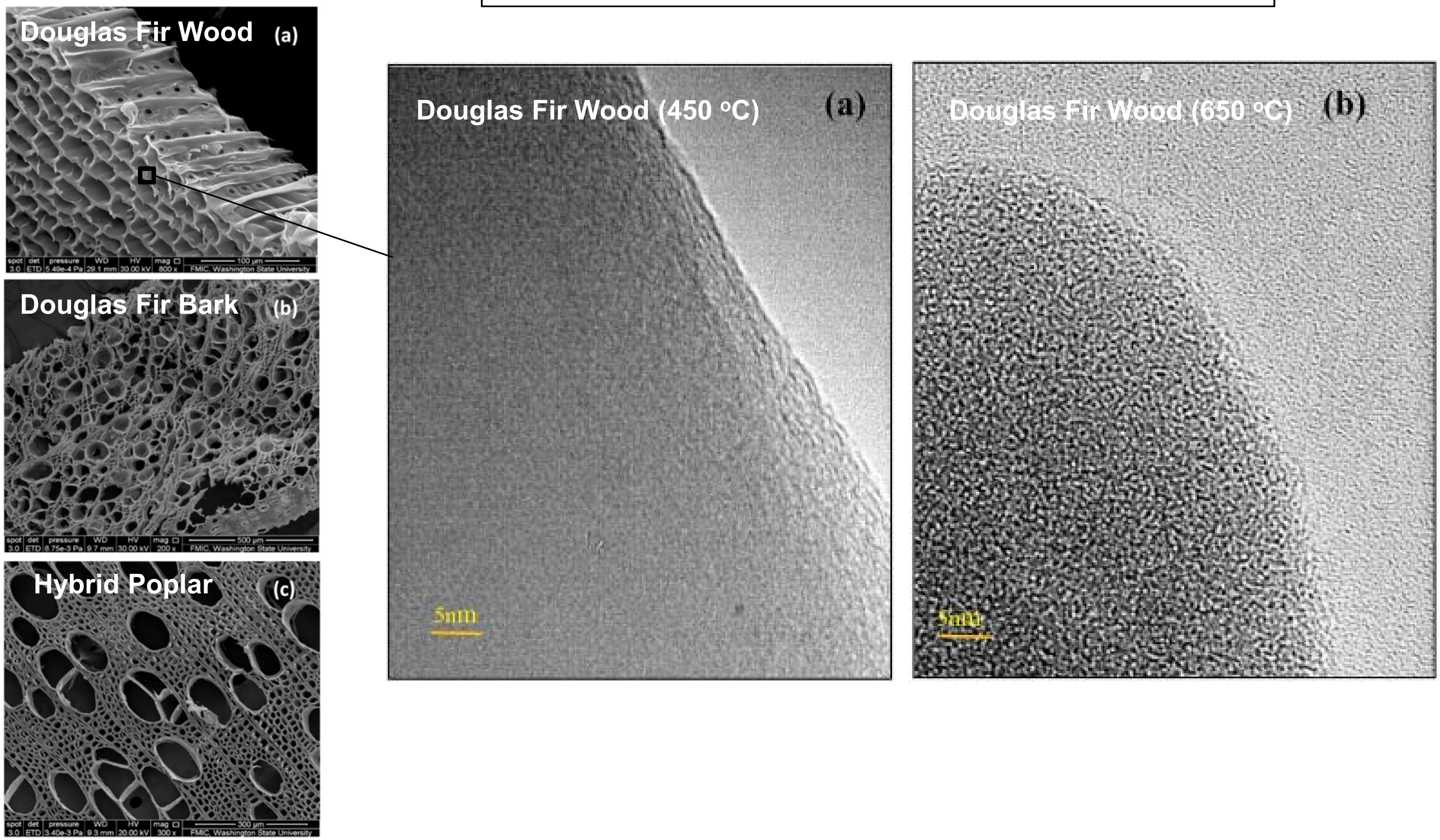
Biochar Properties

SEM and TEM Pictures of Bio-chars



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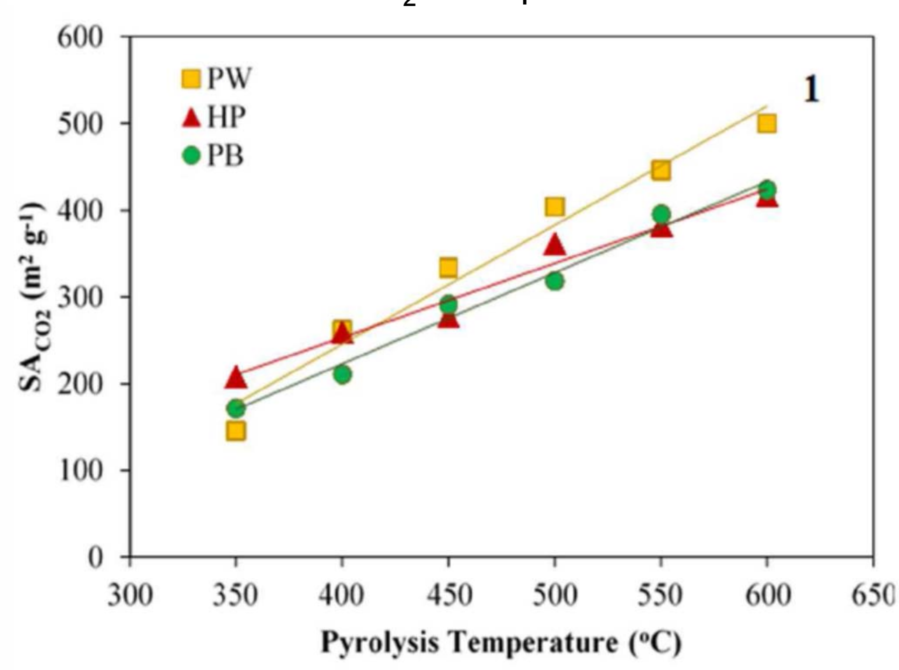
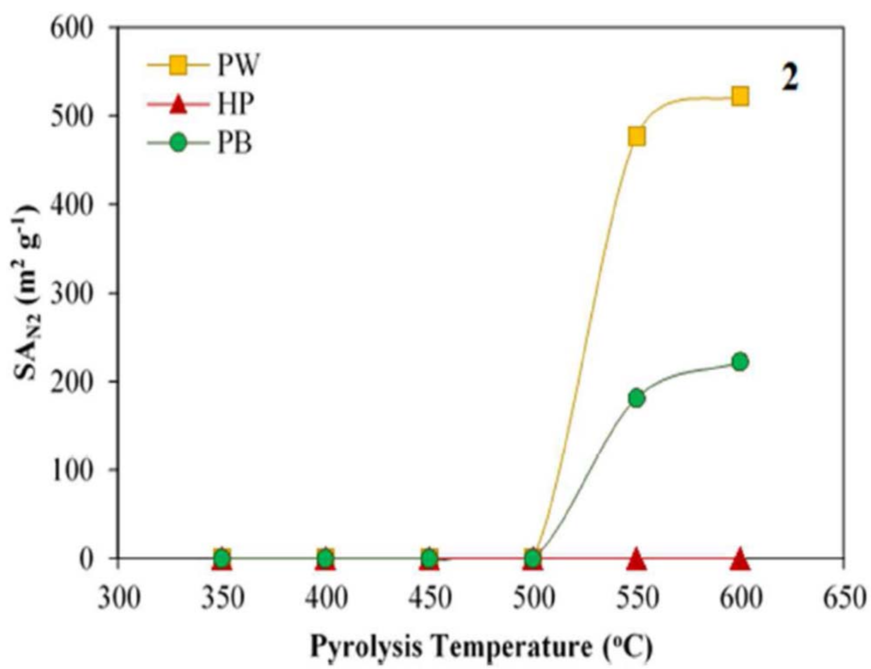
Biochar Properties

Surface Area

CO_2 adsorption



N_2 adsorption



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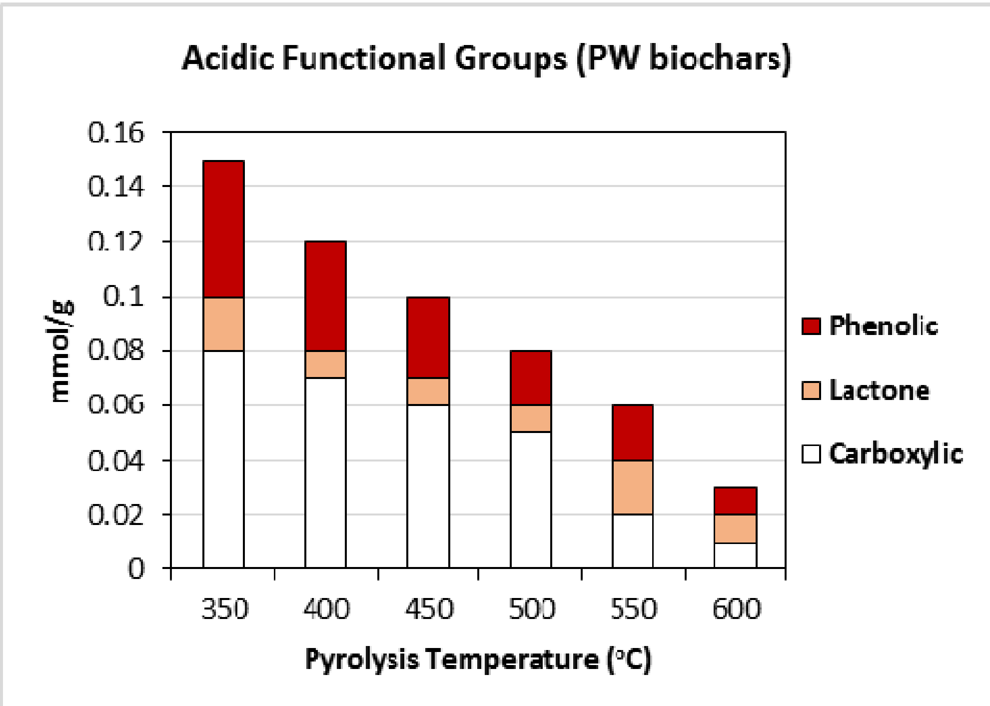
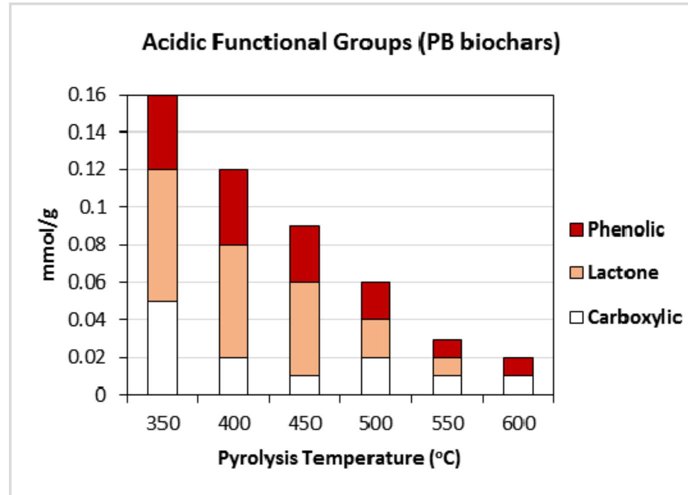
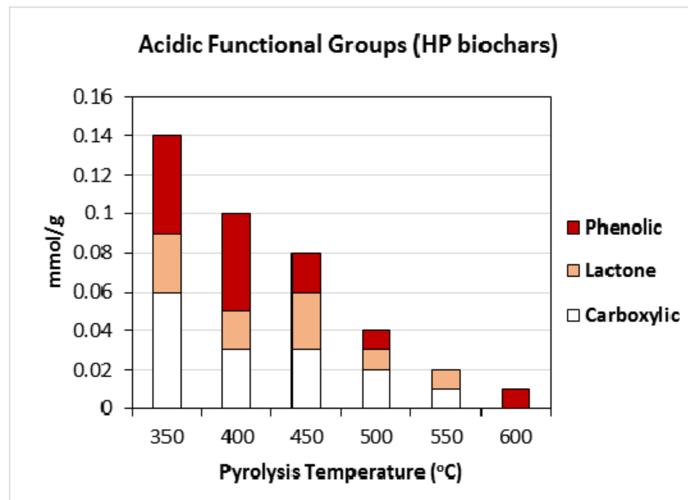
Biochar Properties

Total Acidic Functional Groups (Boehm titration)







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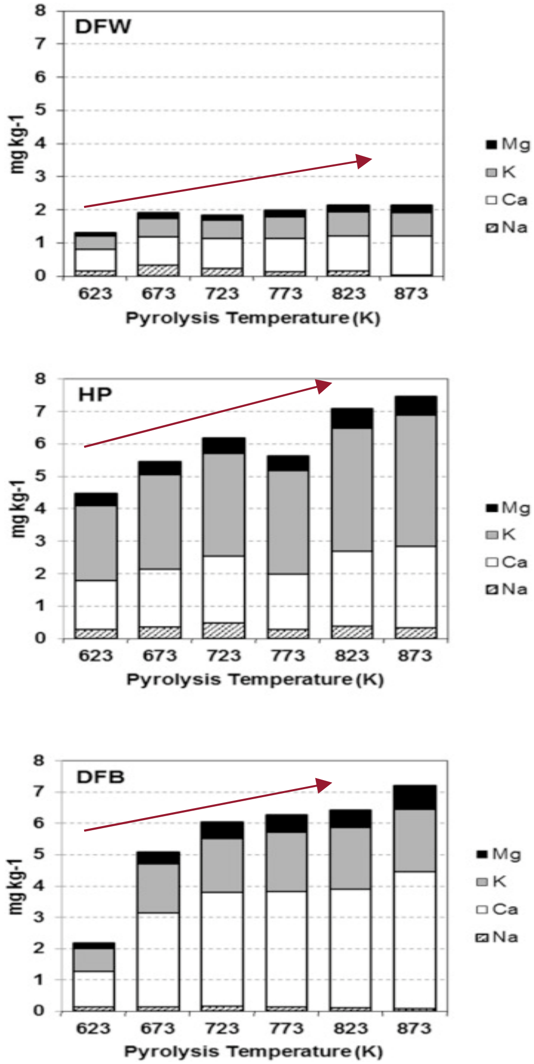
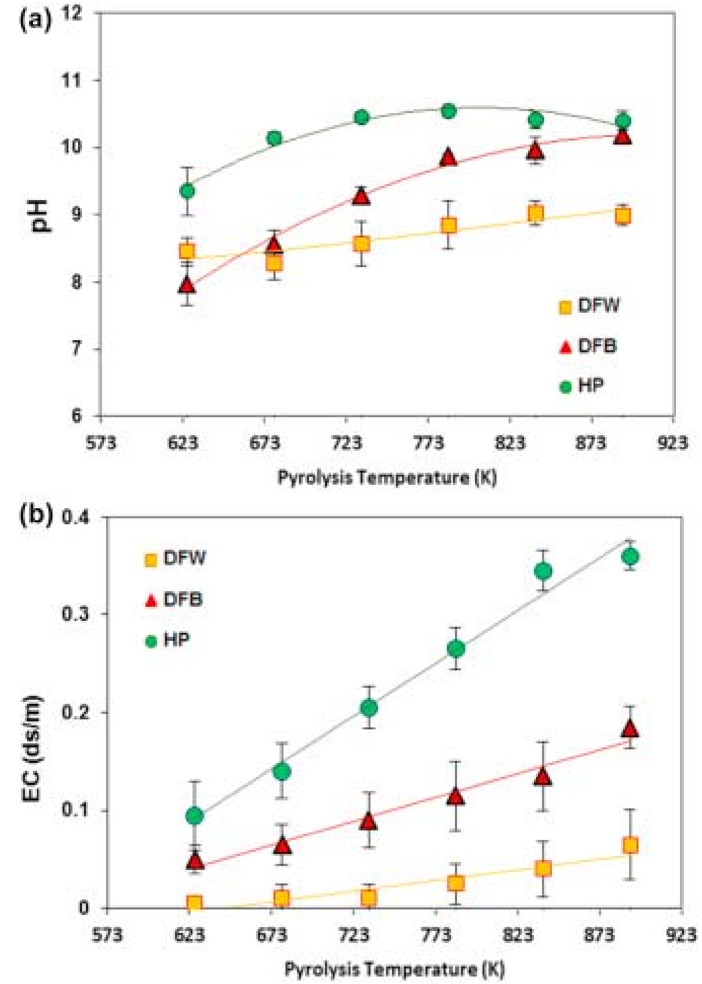
Biochar Properties

Content of Alkalines





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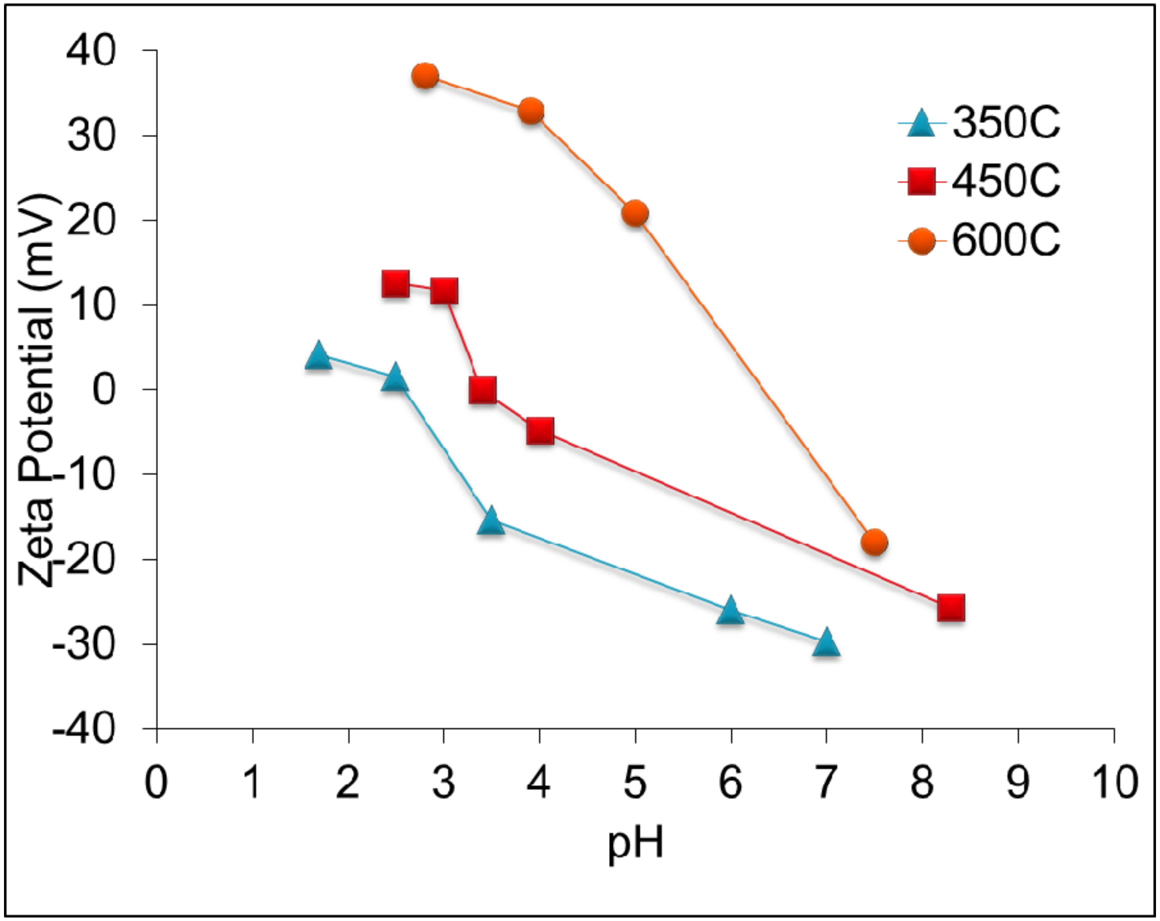
Biochar Properties

Zeta Potential



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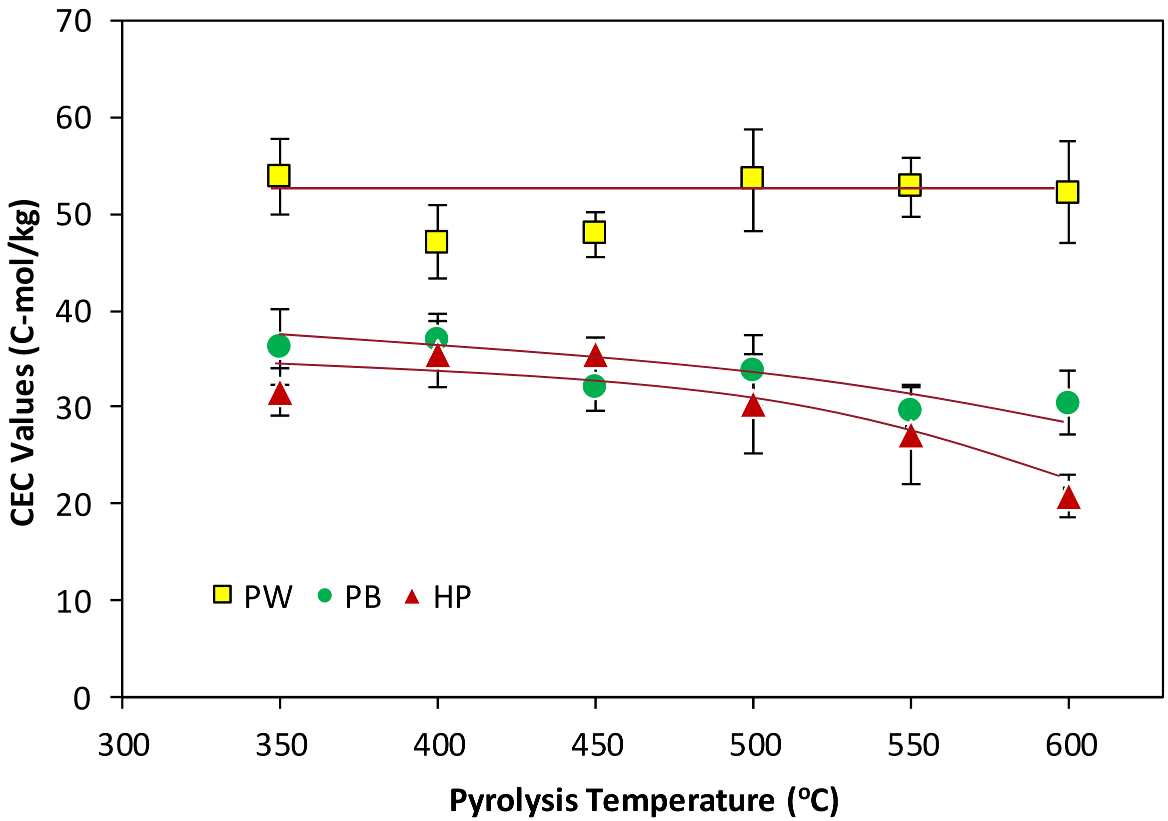
Biochar Properties

Effect of Pyrolysis Temperature on Cation Exchange Capacity



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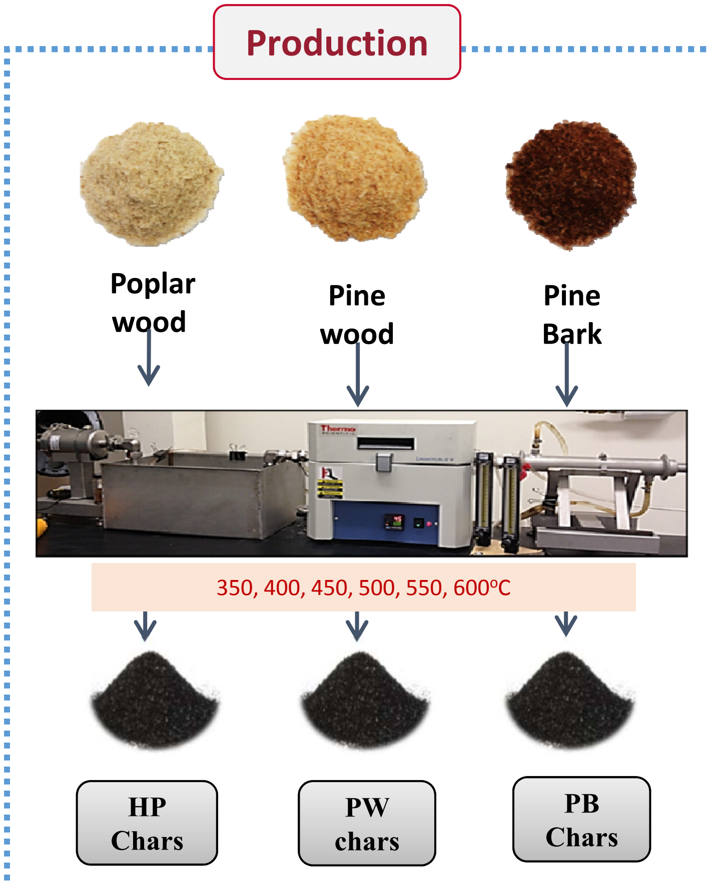
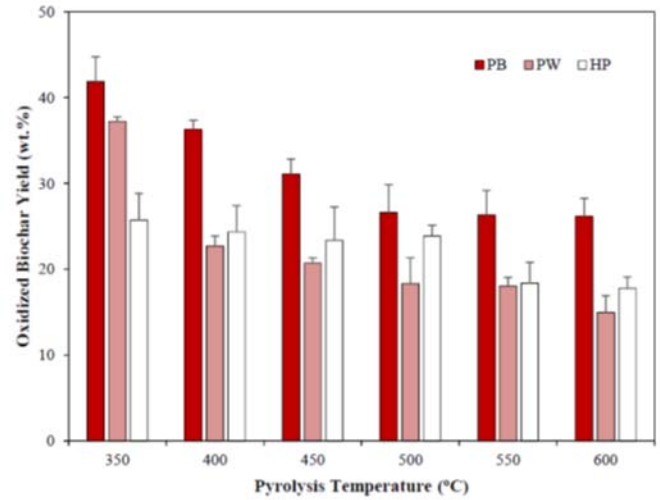
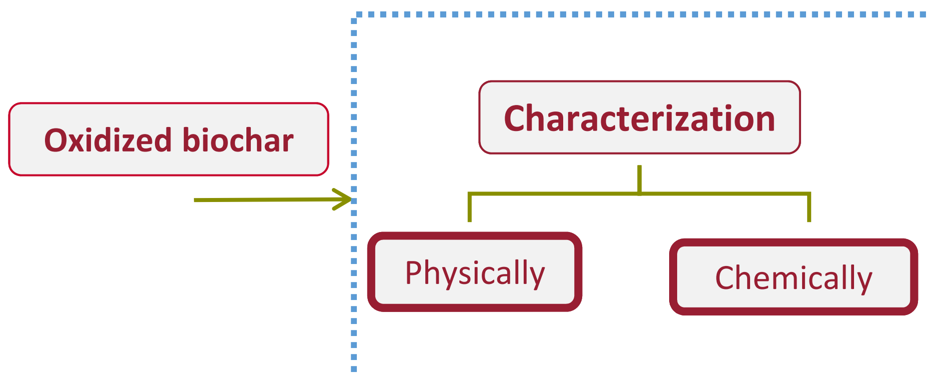
Biochar Properties

Study: Effect of Air Oxidation



Oxidized biochar yields





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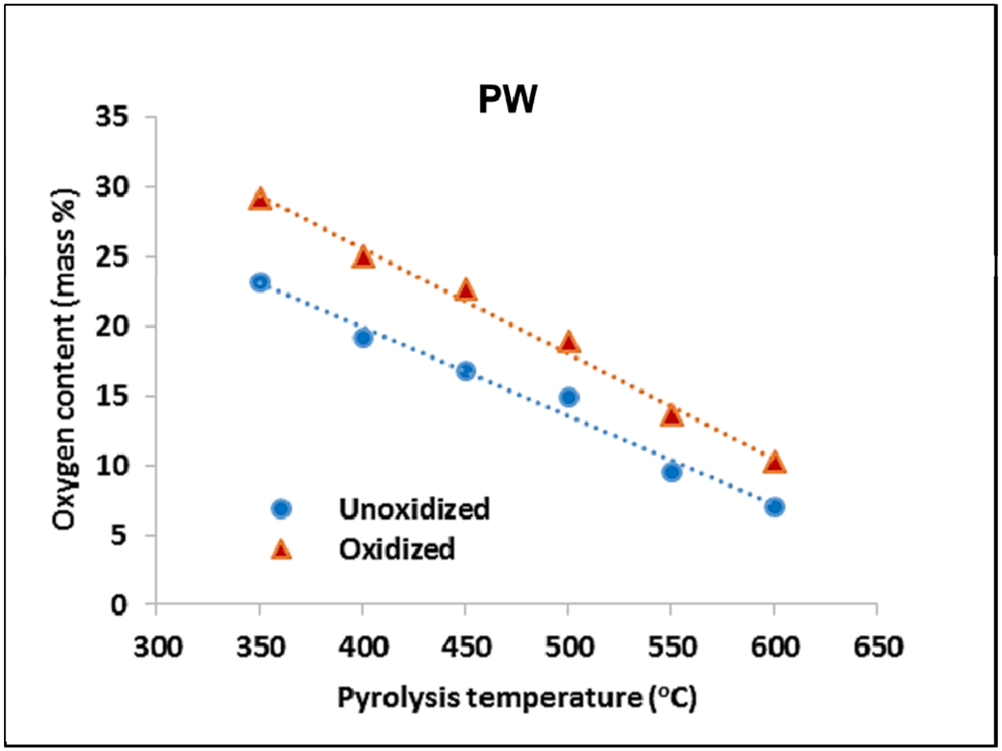
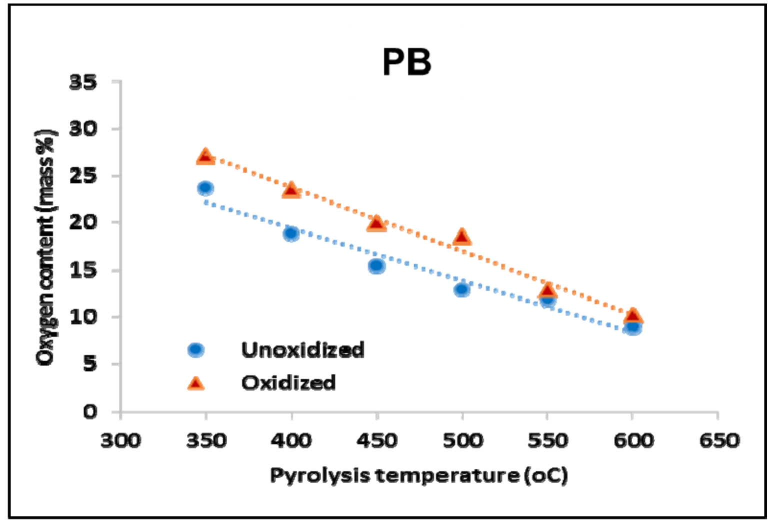
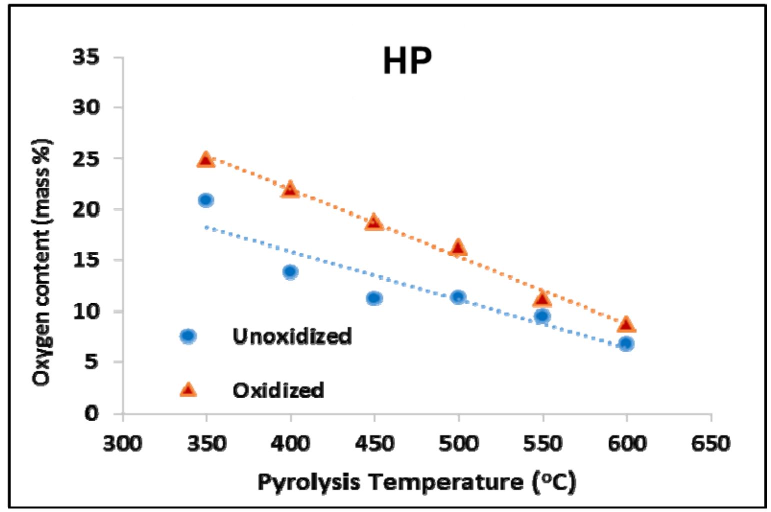
Biochar Properties

Total oxygen content







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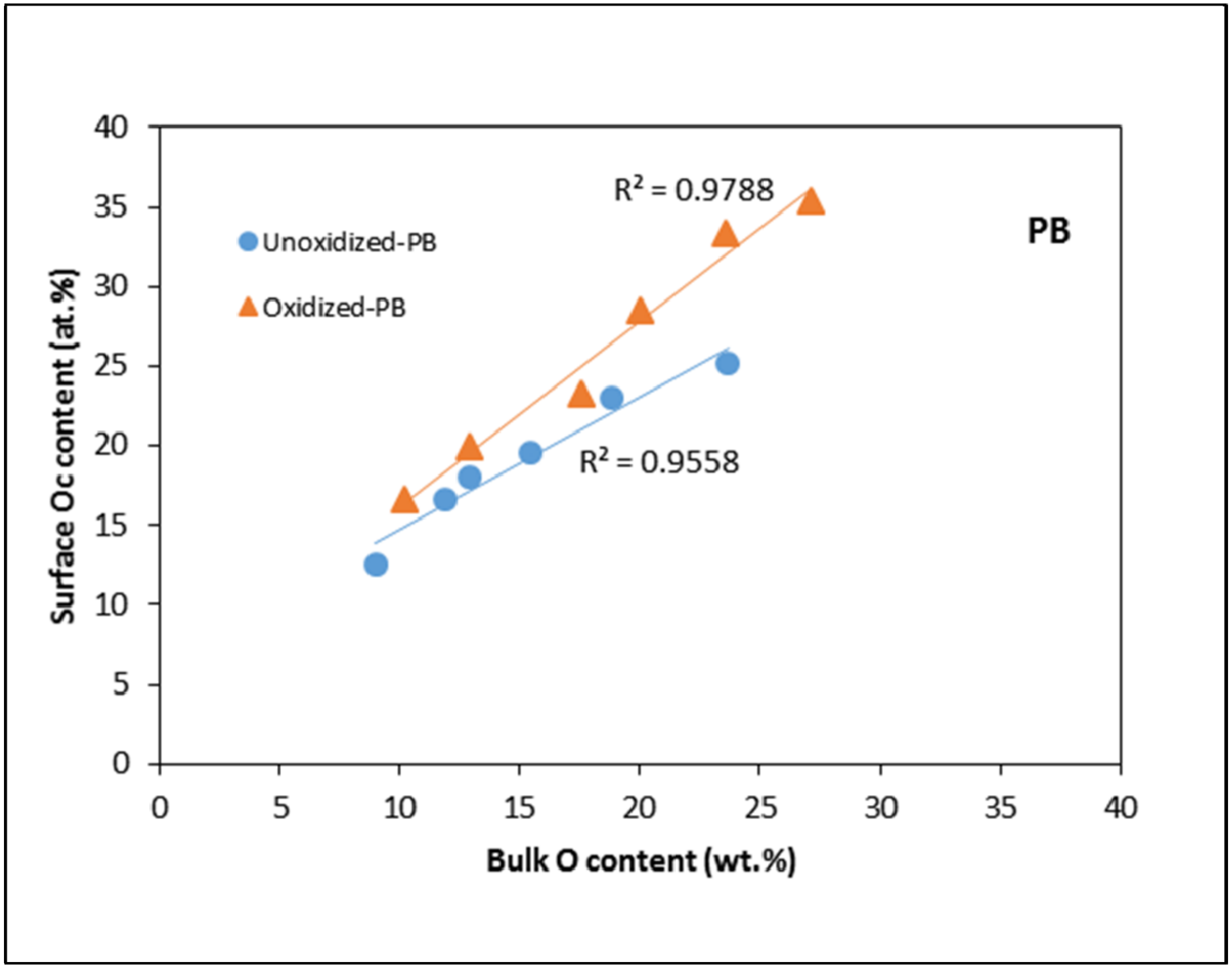
Biochar Properties



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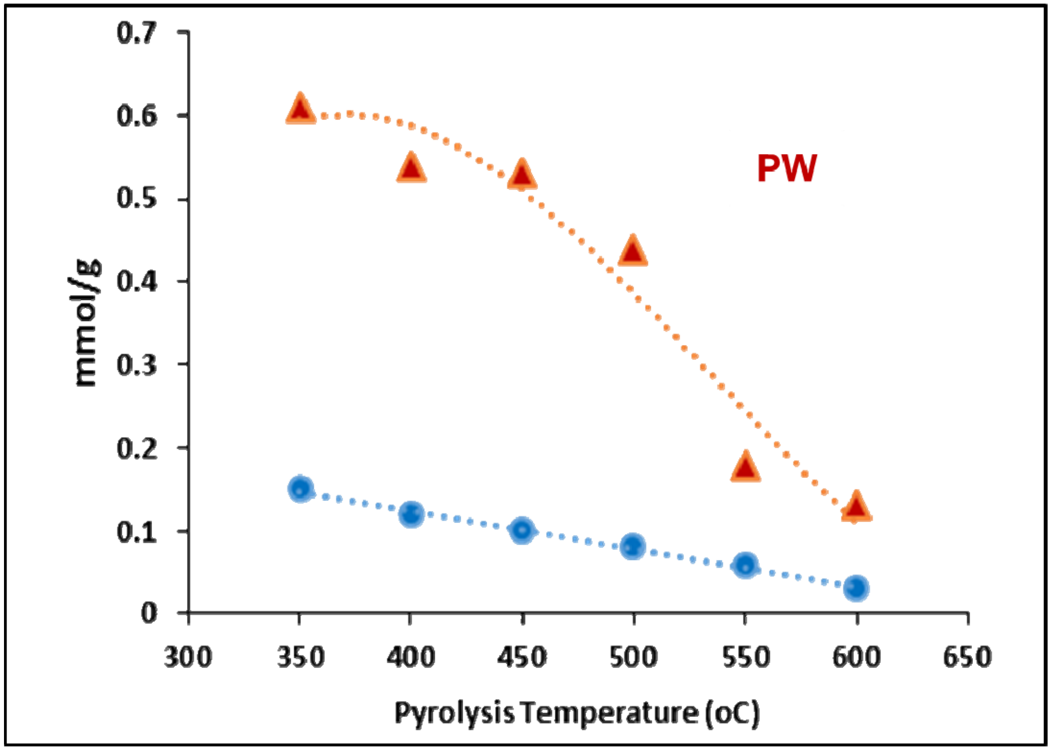
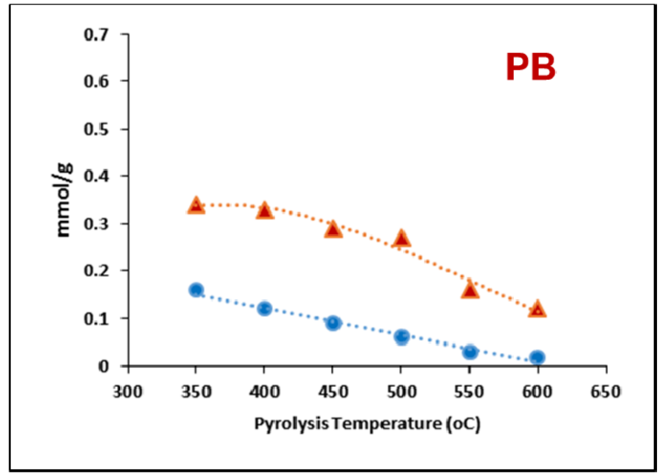
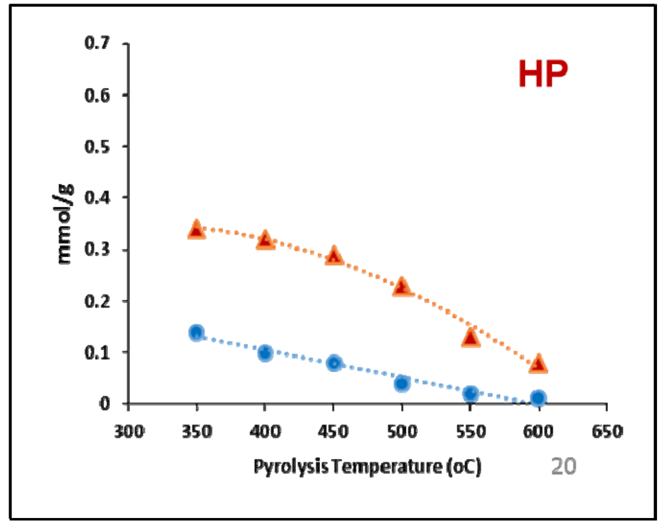
Biochar Properties

Total Acidic Functional Groups
(Boehm Titration)







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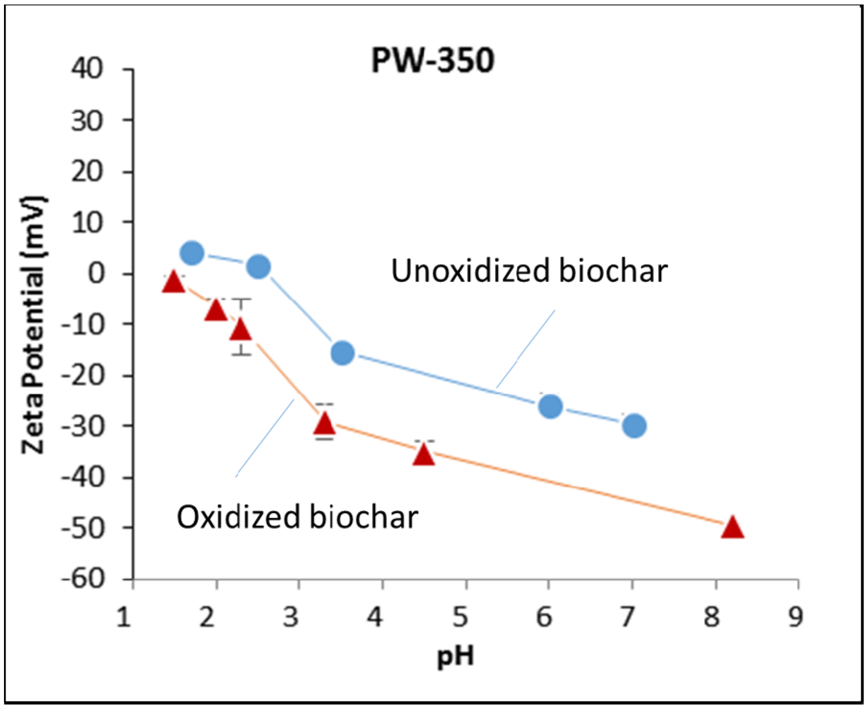
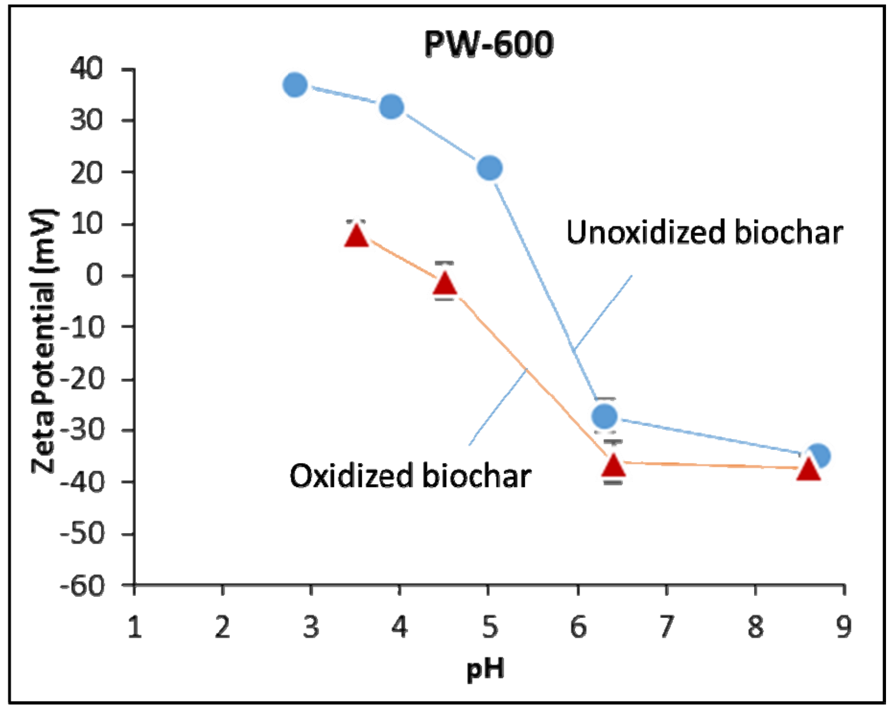
Biochar Properties

Zeta Potentials





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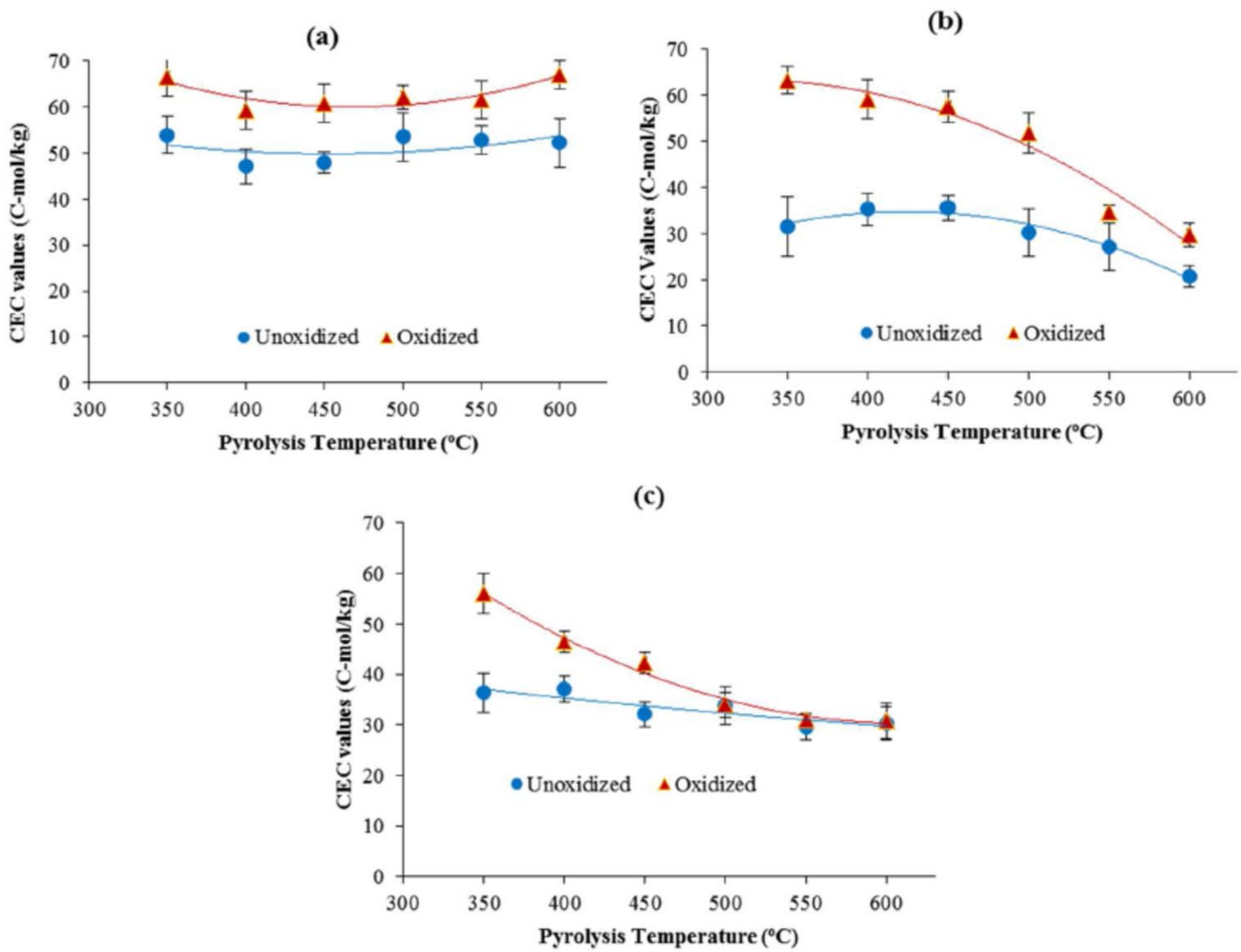
Biochar Properties

CEC values for oxidized and unoxidized biochars



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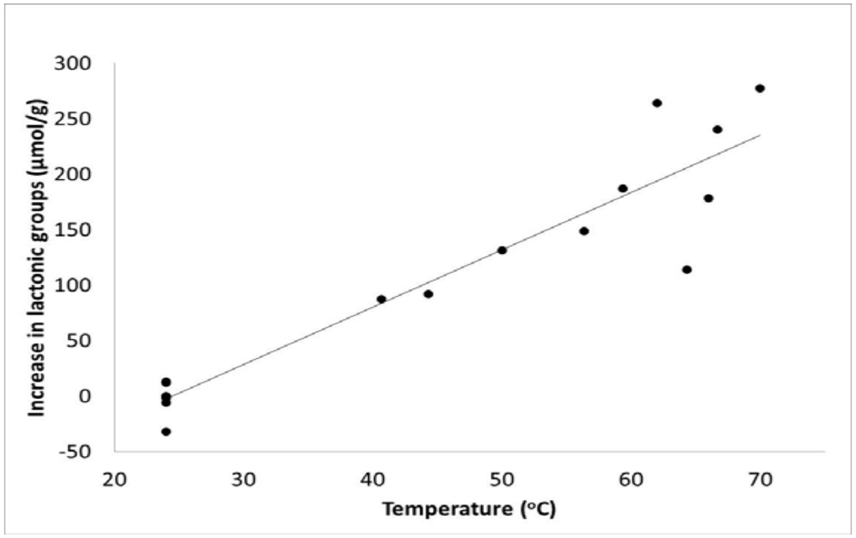
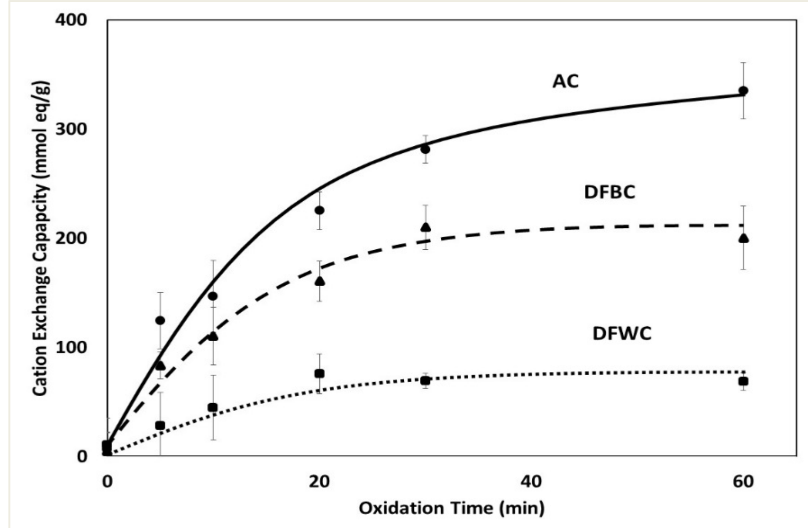
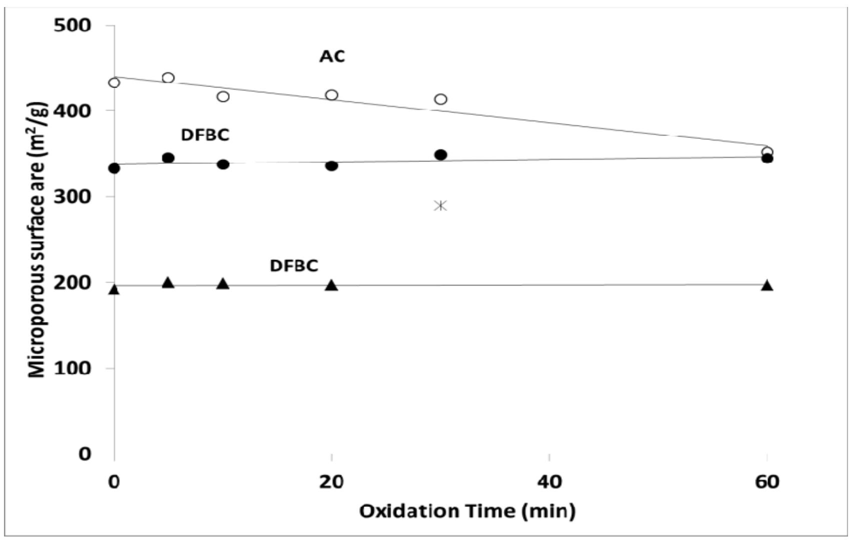
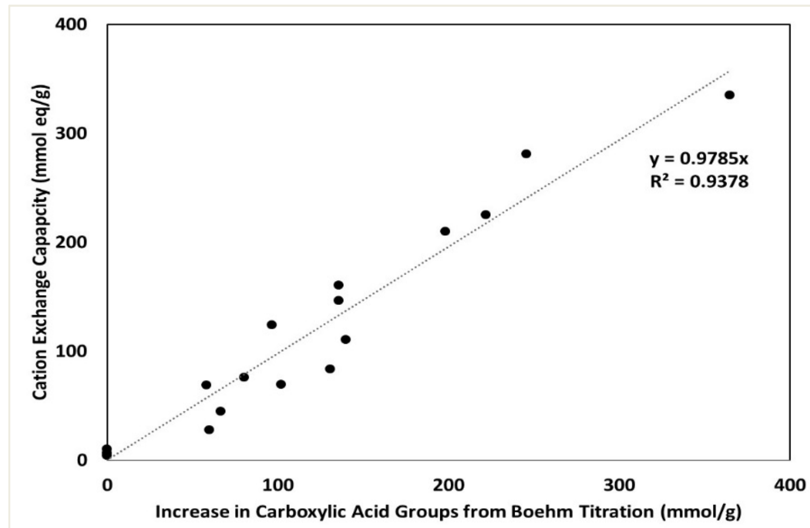
Engineered Biochars

Effect of Post-Pyrolysis Ozonation









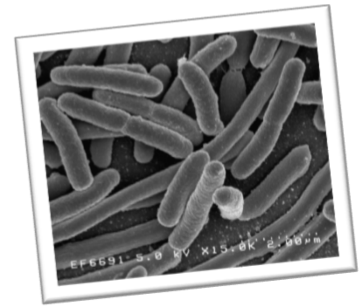
Smith M, Ha S, Amonette JE, Dallmeyer I, Garcia-Perez M: Enhancing cation exchange capacity of chars through ozonation. Biomass and Bioenergy, 81, 2015, 304-314

Environmental Services

Study: E. coli column adsorption experiments

Methodology

- Two strains of ***Escherichia coli*** (with contrasting pathogenicity)
  - *E. coli* K12 ------ non- pathogenic
  - *E. coli* O157:H7 ------ pathogenic



Leached with 10 pore volume of DI water at (16 ml/min)

↓

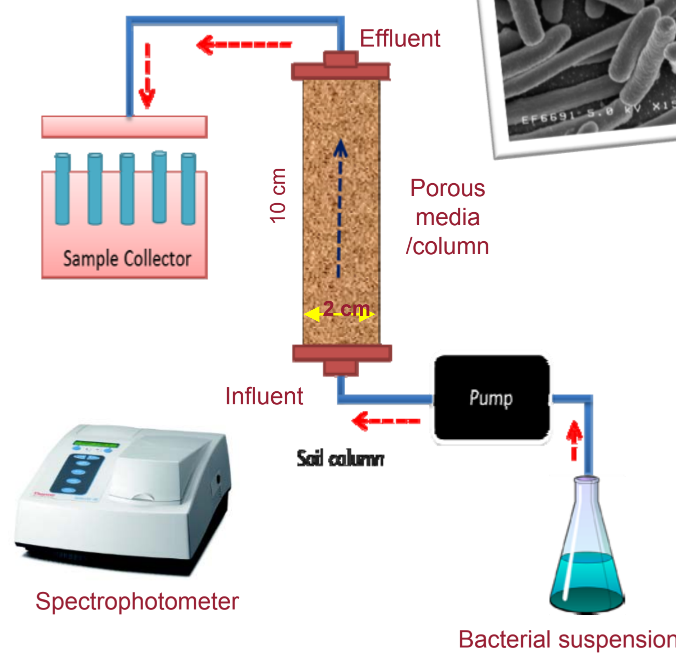
Applied 8 pore volume of bacterial suspension

↓

Leached with 4 pore volumes of DI water

↓

Measured at 600 nm every 16 seconds



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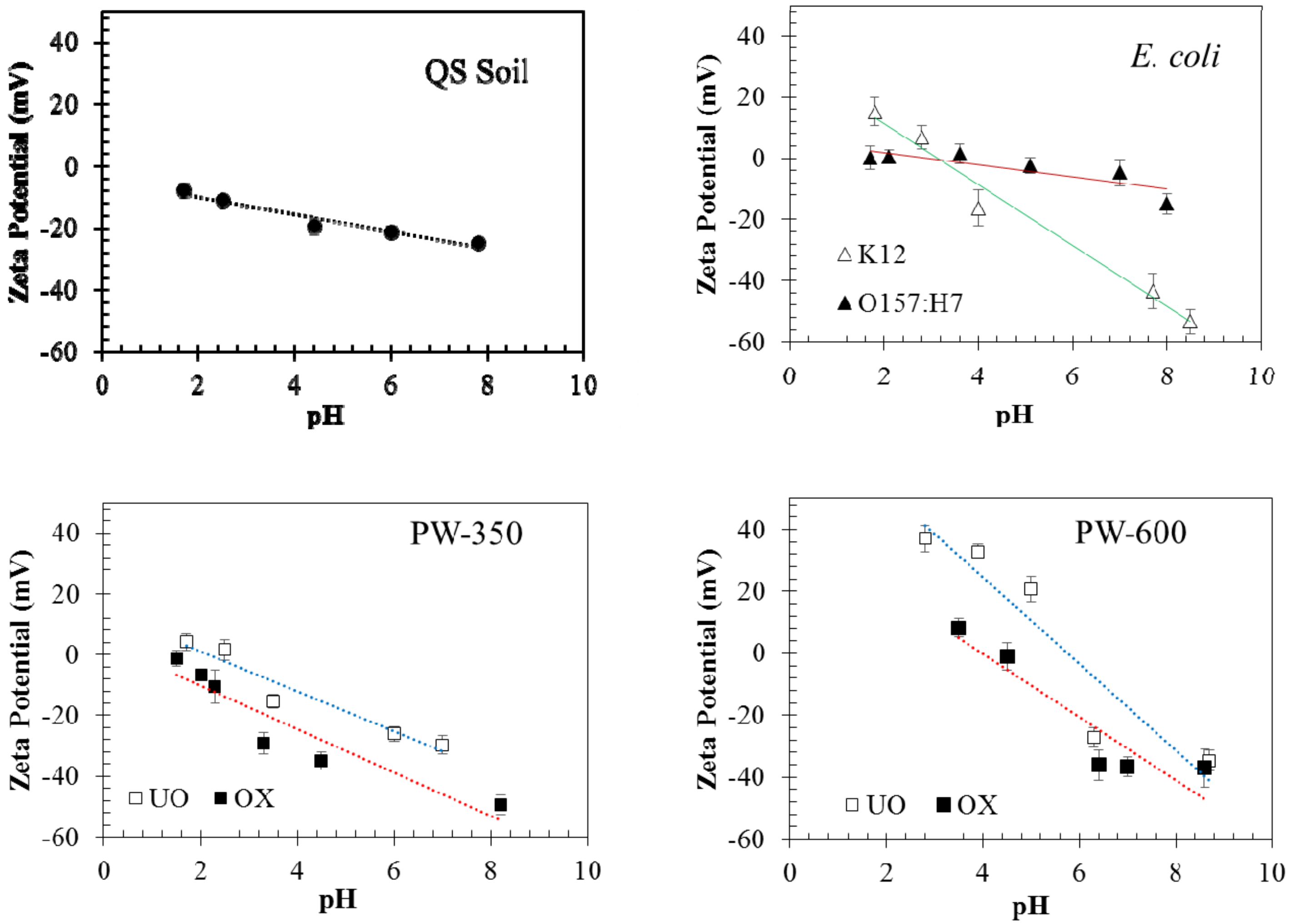
Environmental Services

Z-potential



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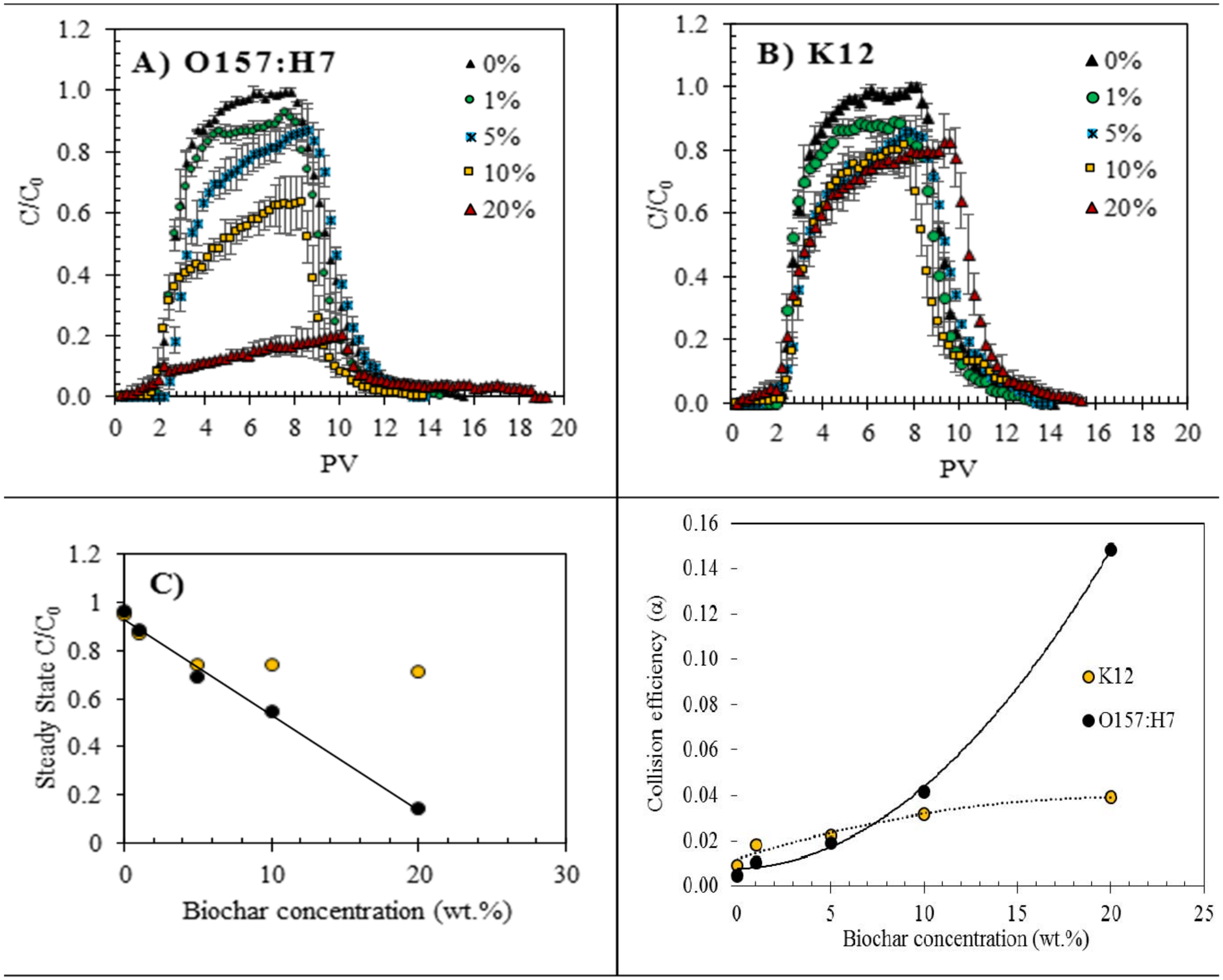
Environmental Services

Effect of Bio-char concentration



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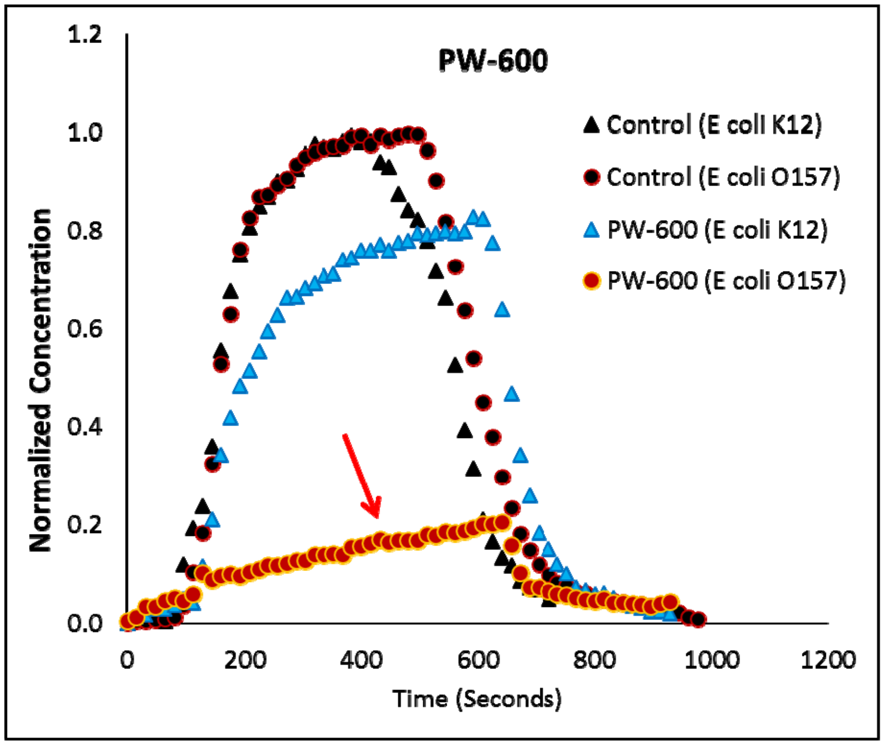
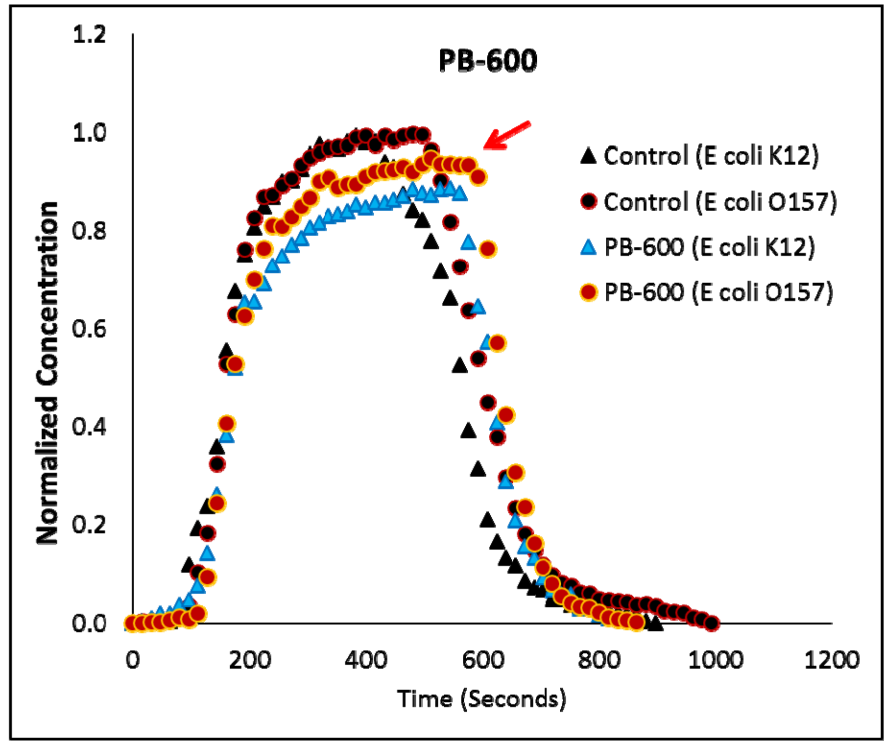
Environmental Services

Effect of Feedstock Source





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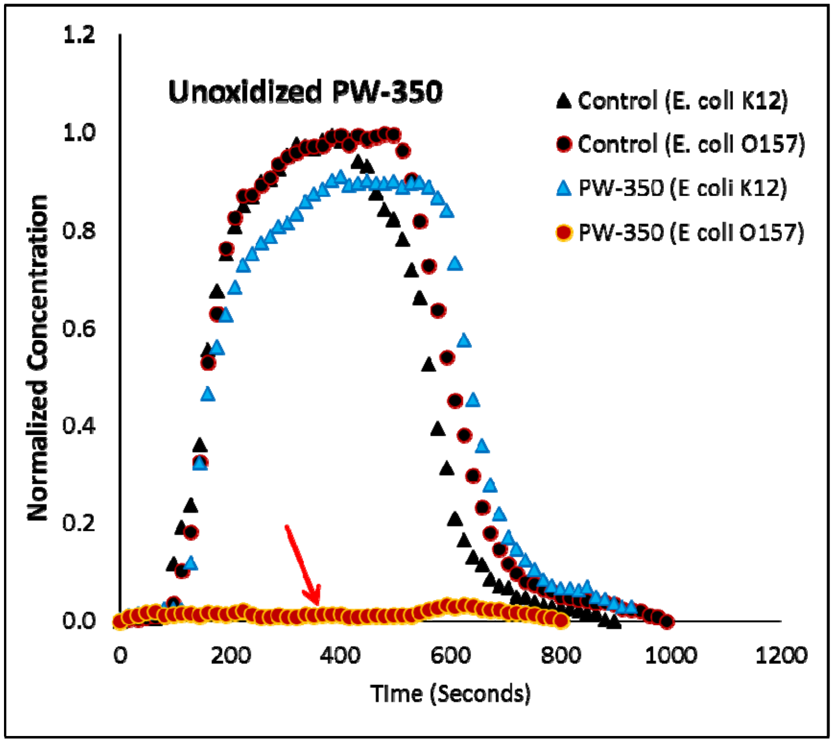
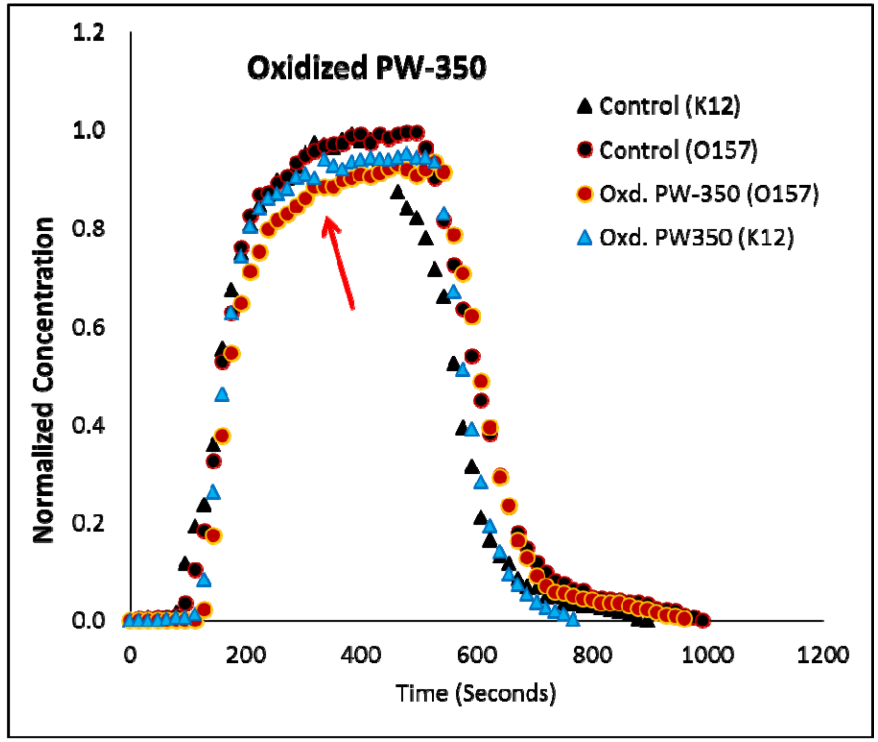
Environmental Services

Effects of oxidation by air





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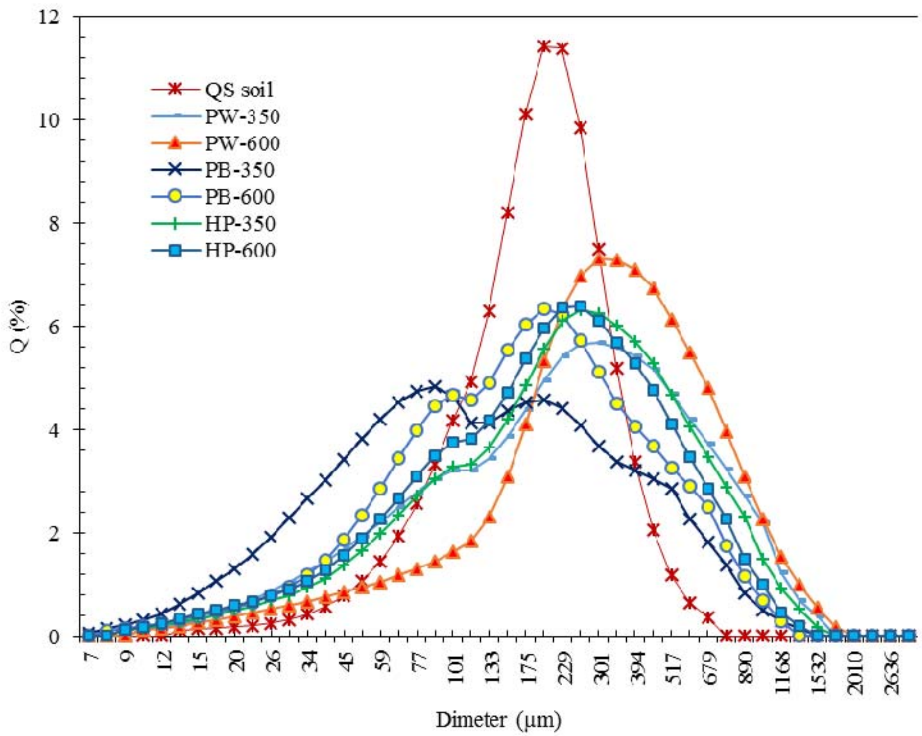
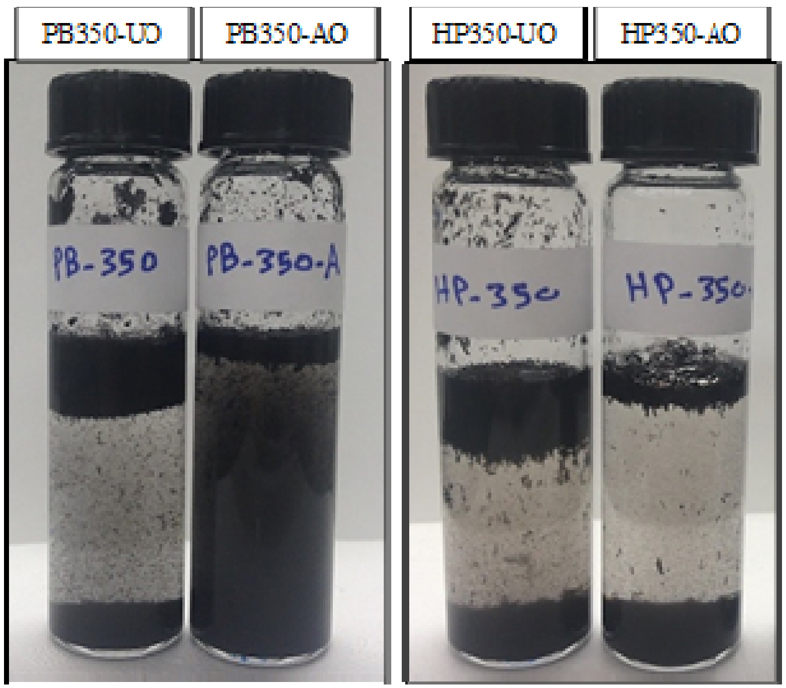
Environmental Services

Water Retention Capacity

Particle size distribution of soil and biochars



Wettability/dispensability of PB350 and HP350, unoxidized (UO) and oxidized (AO)



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Environmental Services

Water Retention Capacity (Biochar blended 20 g/kg)

Hydrophobicity index and water drop penetration time (WDPT) of bio-char

Biochar		Hydrophobicity (MED index)	WDPT (seconds)
QS-PW350	UO	0.7	50
	AO	0.0	0
QS-PW600	UO	0.2	2
	AO	0.0	1
QS-PB350	UO	30.0	>60
	AO	10.0	>60
QS-PB600	UO	1.0	>60
	AO	0.3	10
QS-HP350	UO	10.0	>60
	AO	2.5	>60
QS-HP600	UO	0.9	>60
	AO	0.0	2

Effect of biochar application to sand on bulk density, pH, EC, water contents at field capacity (Θ_{FC}), plant availability (Θ_{AWC}) , and osmotic potentials (O_{sm})

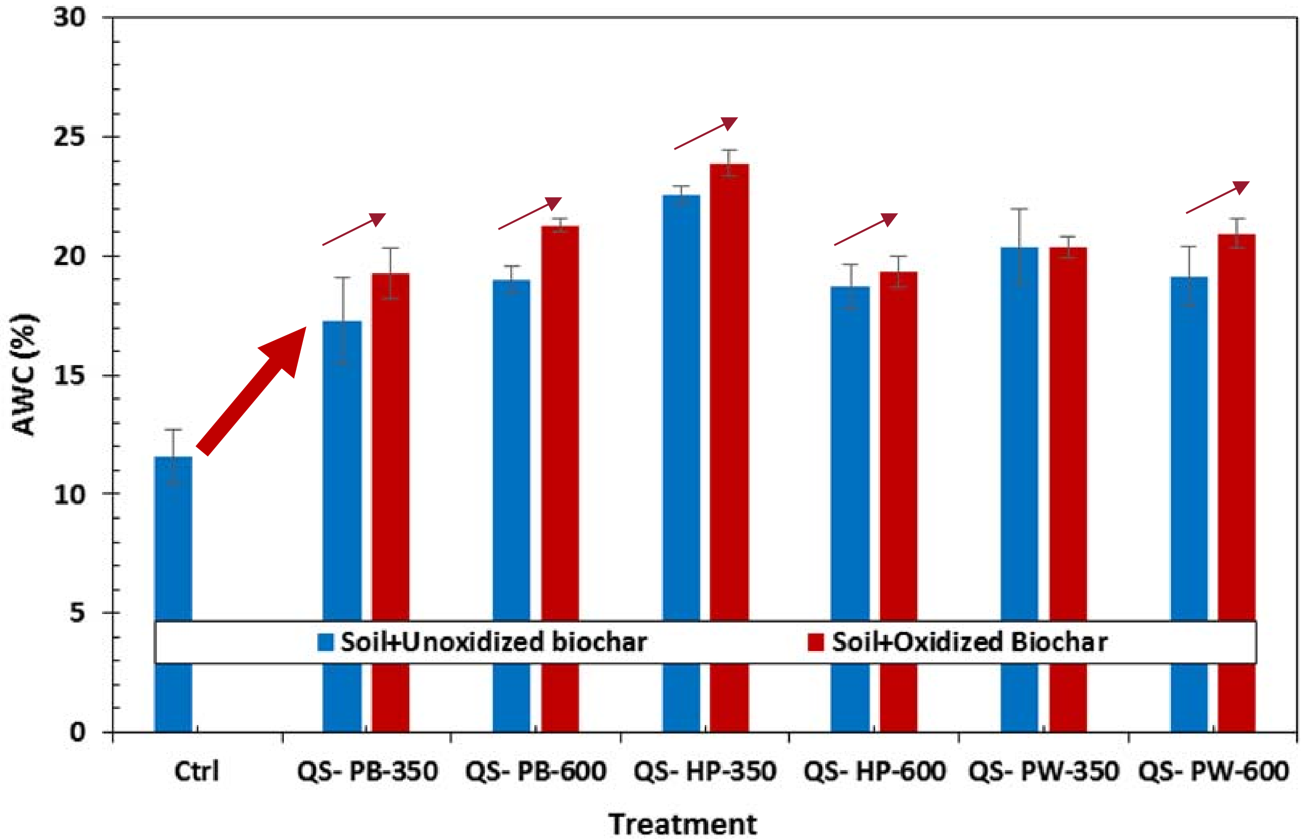
Property	QS	QS-PW350		QS-PW600		QS-PB350		QS-PB600		QS-HP350		QS-HP600	
		UO	AO	UO	AO	UO	AO	UO	AO	UO	AO	UO	AO
Bulk density (g cm^{-3})	1.49	1.27	1.28	1.26	1.27	1.28	1.27	1.29	1.27	1.28	1.26	1.27	1.28
pH_{H2O} (1:5)	7.5	8.1	7.8	8.12	7.9	8.1	7.5	8.7	8.2	8.4	8.1	9.0	8.4
EC_{H2O} (ds m^{-1})	0.08	0.01	0.01	0.02	0.04	0.02	0.03	0.06	0.06	0.03	0.04	0.06	0.05
Θ_{FC} (%)	16.91	26.55	27.09	25.70	27.50	23.68	25.87	25.43	27.18	28.68	30.22	25.50	25.86
Θ_{PWP} (%)	5.32	6.15	6.69	6.56	6.56	6.41	6.60	6.41	5.89	6.09	6.32	6.79	6.52
Θ_{AWC} (%)	11.59	20.40	20.40	19.15	20.94	17.27	19.27	19.02	21.29	22.59	23.90	18.71	19.34
Osm. (-KPa)	2.88	0.36	0.72	0.72	1.44	0.72	1.8	2.16	1.44	1.08	0.36	2.16	0.72

Abbreviations/notes: UO = unoxidized biochar; AO = air-oxidized biochar, WFPS = water filled pore space; Θ_{FC} = water content at Field capacity; Θ_{AWC} = available water content; Θ_{PWP}= water content at Permanent Wilting Point (-1.5 MPa); O_{sm} = osmatic potential.

Suliman W, Harsh JB, Abu-Lail N, Fortuna A-M, Dallmeyer I, Garcia-Perez M: The role of biochar porosity and surface functionality in augmenting hydrologic properties of a sandy soil. Science of the Total Enviornment, 574, 139-147

Environmental Services

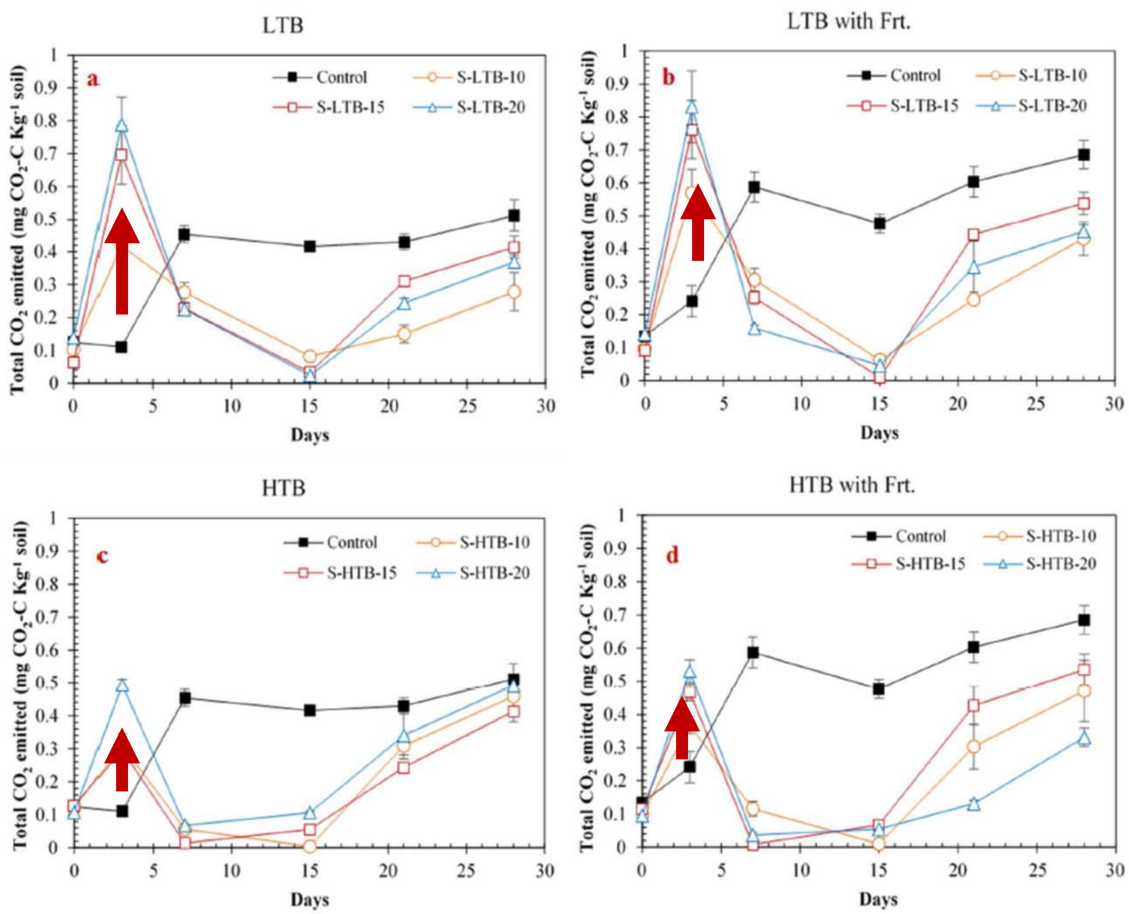
Effect of biochar on Available Water Capacity (AWC)



Suliman W, Harsh JB, Abu-Lail N, Fortuna A-M, Dallmeyer I, Garcia-Perez M: The role of biochar porosity and surface functionality in augmenting hydrologic properties of a sandy soil. Science of the Total Enviornment, 574, 139-147

Environmental Services

CO_2 emissions following application of **Low Biochar Temperature** (**LBT**) (350 ^{o}C) (a and b) and **High Biochar Temperature** (**HTB**) (600 ^{o}C) (c and d) and before N-fertilization (a and c) and after N-fertilization (b and d) (125, 187, and 250 mg char per 50g-1 dry soil by weight or 10,15 and 20 tons/ha)



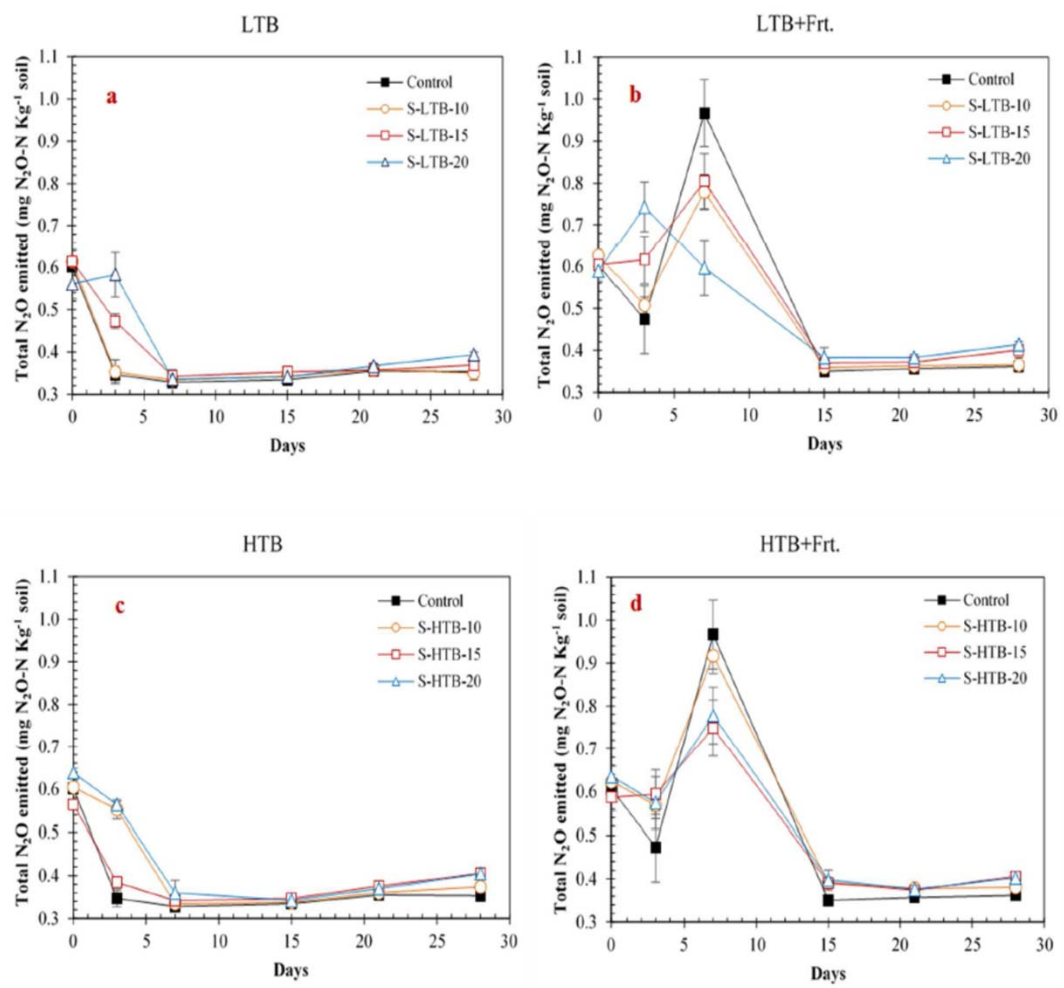
Urea ($(NH_2)_2CO$) was applied at a dose of 1.28 mg 50 g^{-1} soil, which corresponds to 100 kg N ha^{-1}.

No effect of fertilization. Increase in **CO_2** release in first week. High temperature biochar produces less **CO_2** in the initial days.

Suliman W, Harsh JB, Abu-Lail NI, Garcia-Perez M, Fortuna AM: Effect of biochar addition on CO_2 and N_2O fluxes, and inorganic-N contents in quincy sand: A short-term laboratory study. Paper in Preparation, 2017

Environmental Services

N_2O emissions following application of LBT biochar (a and b) and HTB biochar (c and d) and before N-fertilization (a and c) and after N-fertilization (b and d)

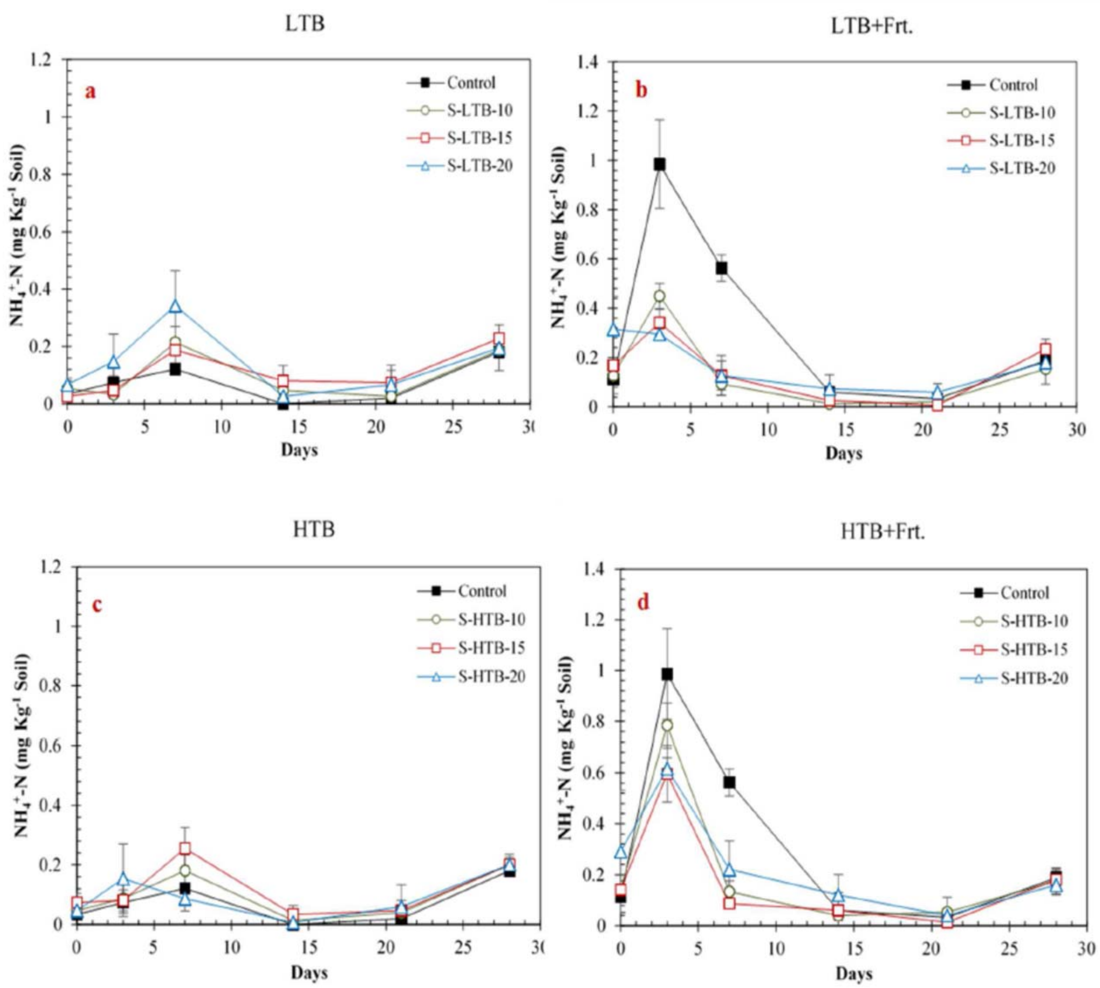


Emissions of **N_2O** from the biochar amended microcosms were generally lower than from controls (soil alone) during the first 7 days, but after day 14 there was no significant difference

Suliman W, Harsh JB, Abu-Lail NI, Garcia-Perez M, Fortuna AM: Effect of biochar addition on CO_2 and N_2O fluxes, and inorganic-N contents in quincy sand: A short-term laboratory study. Paper in Preparation, 2017

Environmental Services

NH_4^+-N emissions following application of LBT biochar (a and b) and HTB biochar (c and d) and before N-fertilization (a and c) and after N-fertilization (b and d)

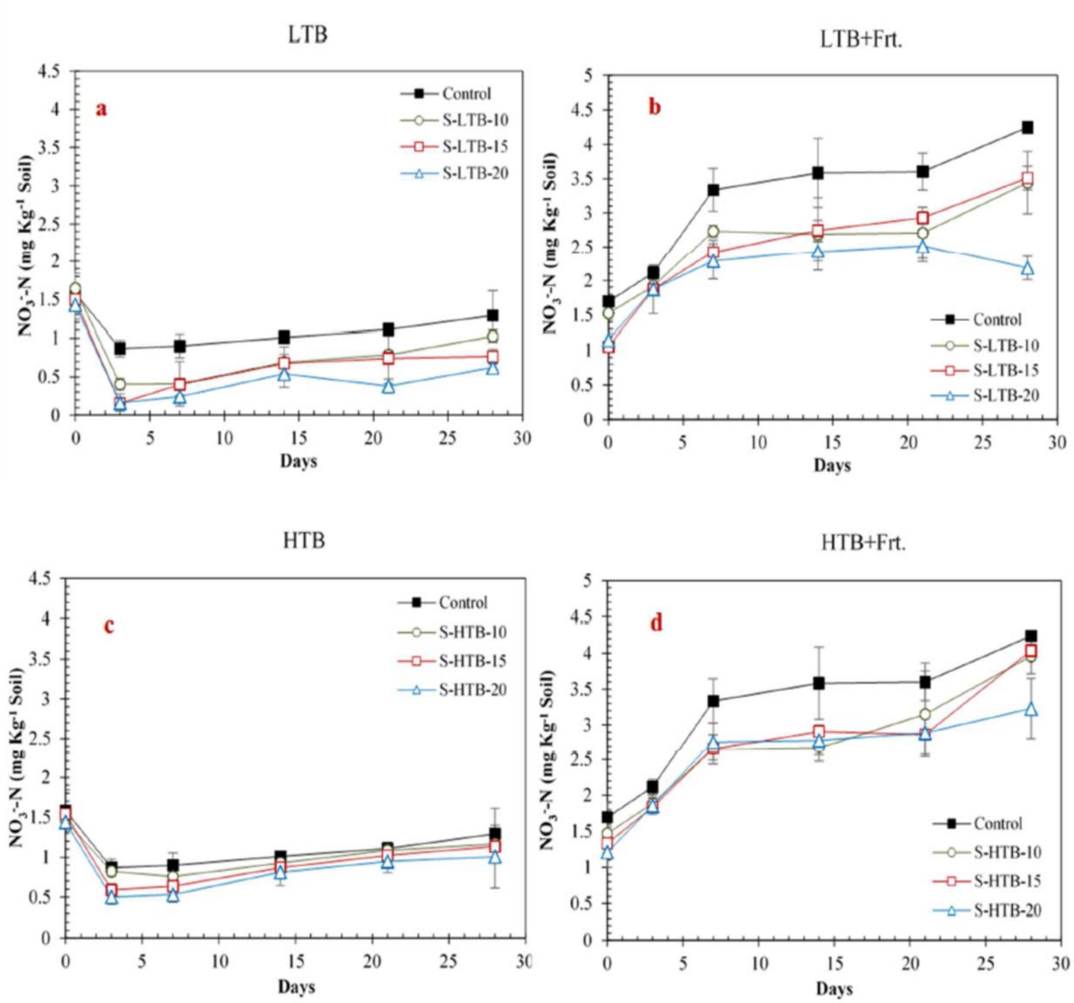


The inorganic N pool was clearly influenced by biochar addition; **NH_4^+** differed between treatments. More release in control.

biochar addition on CO_2 and N_2O fluxes, and inorganic-N contents in quincy sand: A short-term laboratory study. Paper in Preparation, 2017

Environmental Services

$NO_3^{—}$N emissions following application of LBT biochar (a and b) and HTB biochar (c and d) and before N-fertilization (a and c) and after N-fertilization (b and d)



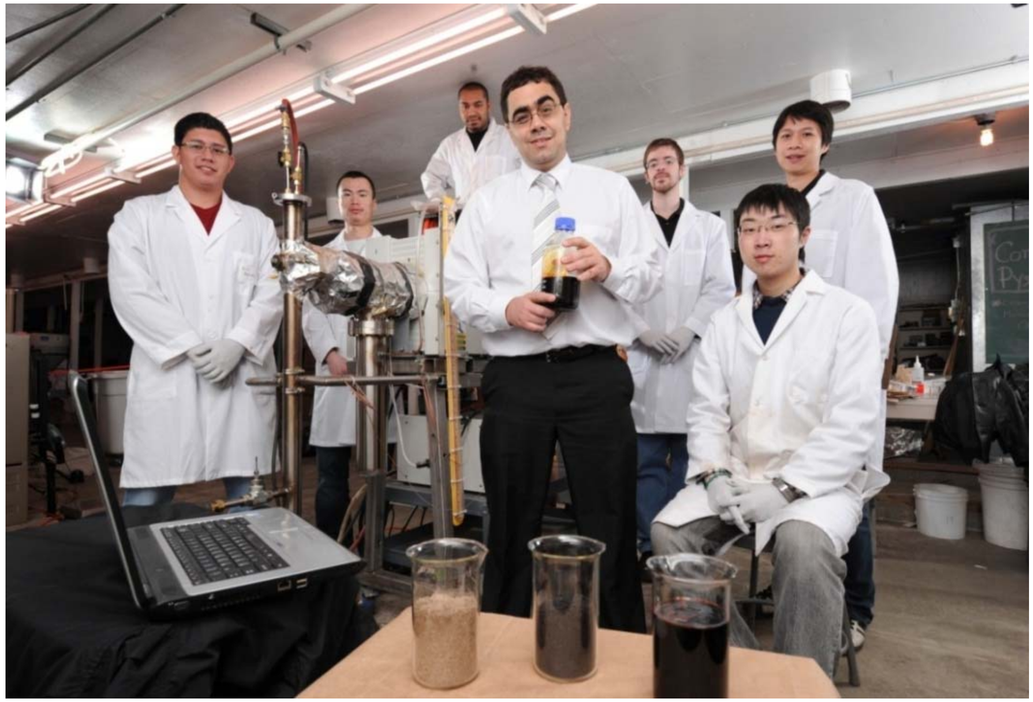
The inorganic N pool was clearly influenced by biochar addition; NO_3 decreased as biochar doses increased

Suliman W, Harsh JB, Abu-Lail NI, Garcia-Perez M, Fortuna AM: Effect of biochar addition on CO_2 and N_2O fluxes, and inorganic-N contents in quincy sand: A short-term laboratory study. Paper in Preparation, 2017

Conclusions

- Pyrolysis temperature and feedstock material are important parameters controlling biochar bulk and surface physico-chemical characteristics.
- Biochar susceptibility to low temperature oxidation was thoroughly studied. The XPS and Boehm titration confirmed it is much easy to oxidize bio-chars produced at low temperature. The formation of oxygenated functional groups contributes to add negative charges on the surface and consequently the pH at the point of zero charge.
- The mechanisms associated with the adsorption of e-coli in bio-chars was studied. Pine wood biochar produced at low temperature was effective in reducing the transport of E. coli in the studied soil.
- Biochars have an excellent water retention capacity. Water retention capacity increases if the bio-char surface is oxidized.
- The effect of high temperature chars was higher in gases retention. Cumulative N_2O production within 28 days of the experiments was not affected by biochar addition.

ACKNOWLEDGEMENT



We would like to thank the funding agencies supporting my Research Program

WASHINGTON STATE UNIVERSITY AGRICULTURAL RESEARCH CENTER

U.S. NATIONAL SCIENCE FOUNDATION

WASHINGTON STATE DEPARTMENT OF AGRICULTURE

SUN GRANT INITIATIVE, U.S. DEPARTMENT OF TRANSPORTATION, USDA

WASHINGTON STATE DEPARTMENT OF ECOLOGY

U.S. DEPARTMENT OF ENERGY

Thank you ☺

Questions?